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Study of Psychophysical Factors of Vision and Pyrotechnic Light Sources

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Technical Report AFATL-TR-68-17

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STUDY OF PSYCHOPHYSICAL FACTORS OF VISION AND PYROTECHNIC LIGHT SOURCES

R. M. Blunt
W. A. Schmeling

FOREWORD

This study was performed during the period 18 October 1966 to 18 December 1967 by Mr. R. M. Blunt and Mr. W. A. Schmeling of the Mechanics Division, Denver Research Institute, University of Denver, for the Illumination Branch, Targets and Missiles Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida under Contract F08635-67-C-0018. The study was initiated by Mr. William S. Cronk (ATTI) and monitored for the sponsor by Mr. L. W. Moran (ATTI).

Contributions in special areas of this program were made by Mr. Ralph Williams, who prepared the pyrotechnic tables and by Messrs. William Jurney, Georg Becker, and Vincent Miller. These contributions are gratefully acknowledged.

Classified reports were reviewed during this study and are referenced in the bibliography. It has not been necessary to use material from classified reports that is not also available in the open literature.

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A J Cupper

A. J. CUPPER, Lt. Colonel, USAF
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ABSTRACT

A detailed survey of the open and classified literature on pyrotechnics and vision has been made. A limited amount of experimentation was done to investigate the effectiveness of flickering colored light sources on target detection. The physical data on the composition of, and radiation from, green, red, blue, yellow and white flare compositions have been presented in summary tabulations. A bibliography of the reports and journal articles that were used in this study is presented. The index lists the 461 entries by category; vision and visibility, pyrotechnic light sources, targets and background, psychological factors. It is concluded that the most generally applicable method of improving detection of targets is simply that of minimizing glare in the observer's eyes and maximizing the illumination at the target area. None of the subtle effects proved to increase detectability appreciably. The best pyrotechnic illuminant available is the sodium nitrate-magnesium flare. It appears that improvement of pyrotechnic sources can be accomplished by investigating other compositions which are selective radiators in the visible region of maximum response, with minimal radiation in all other regions. A large number of tables and graphs are presented which are useful in determining visibility and illumination parameters.

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SECTION I

INTRODUCTION

The research described in this report was done in order to correlate the requirements of visual night reconnaissance with the capabilities of pyrotechnic sources of illumination.

The motivation stemmed from the observation that, across a span of thirty years or more, much research had been done to elucidate the mechanisms of the seeing process. A great deal of this was of a purely physiological content, or was primarily psychological in its approach. A fraction was specifically directed toward military problems of visual reconnaissance. Much good work had also been done to improve the illuminating ability of pyrotechnic devices. Still, there did not appear to be any one source to which reference could be made when questions arose concerning the optimum use of pyrotechnics in visual reconnaissance.

This study, as a result of its motivation, represents an effort to correlate the research reported in the literature, condensing it and providing a single concise reference volume.

In the course of the work, it has been apparent that a great deal of good work in the pyrotechnic area has been of less than full value. This results from the lack of a uniform, consistent method of measurement and reporting for the values of color, purity, intensity and energy output. It would reduce the cost of future research - by avoiding repetition of tests - if consistent and comprehensive methods of measurement and reportage could be accepted by the private and Governmental laboratories working on pyrotechnics.

A similar study of the material available in the literature which describes the vision aids that are activated by ultraviolet or infrared light should be made. It could be based in part on material collected during this study and thus accomplished more easily and economically. It is believed that a companion study of this nature would complete the survey begun here and provide a firm basis for the planning of future work.

The organization of this report is based on the following major categories: Observer, Source, Target. The entire matter revolves

about the observer, since detection by seeing is the whole object of visual night - or day - reconnaisssance. Next to the observer, an effective source is essential - without one, the most obvious target would remain invisible. The target is certainly the object to be discerned by the observer by the aid of the source and its size, color and contrast are next of importance.

SECTION II

THE OBSERVER

1. GENERAL

A description of the observer's part in the detection of a target may be divided conveniently into the essentially physiological factors and the psychological factors. The physiological factors are those that control the admission of light to the eye, the formation of an image on the retina, translation into neural impulses and transmission to the brain for processing. The psychological factors are produced from the neurological signal in the brain and relate to the apparent size, shape, color, motion, and distance of the target object.

A discussion of vision would seem to require a description of the anatomy and functioning of the eye. The following description, modified to suit present needs, is taken from the Society of Automotive Engineers Publication SP-279, March, 1966. (1)

2. THE EYE

a. Anatomy

"Figure 1 is a schematic drawing of the essential parts of the eye. These parts, labeled in the direction of the incident light, are: the cornea, the iris forming the pupil, the anterior and posterior chambers filled by the clear aqueous humor, the crystalline lens, the vitreous body (a gel-like clear substance filling the space between the lens and the inner-most layer of the eyeball), and the retina which contains the phototransducing elements. Figure 2 (after Troncoso) shows the view of the fundus as obtained when looking through the pupil with an ophthalmoscope. The central dark area is the macula (M) which is slightly more pigmented than the rest of the fundus with the fovea (F) at its very center, which mediates our sharpest vision. The area near the fovea is called the parafovea. It is surrounded by the perifoveal and farther periphery with the vessels and the optic nerve head (O), also called disc, where the nerve fibers from the retina leave the eyeball, forming the optic nerve. The optic disc is a blind area because the photoreceptors are lacking in this area. Figure 3 shows the distribution of the receptors in the retina. They are of two types, the cones and the rods. Generally speaking, the cones serve daytime vision, and the rods serve vision in dim illumination. The cones are most

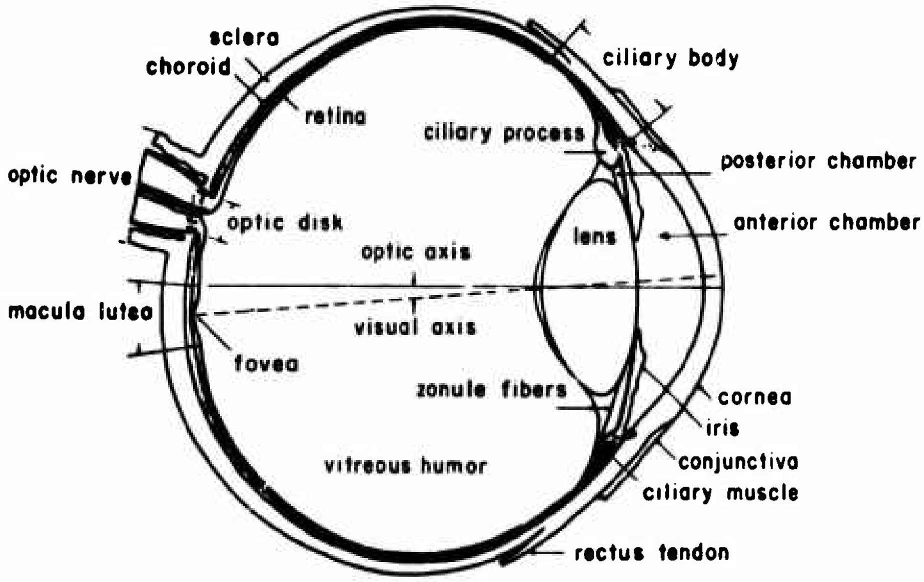

Figure 1. Horizontal Section of the Right Human Eye

Figure 2. Fundus of the Human Eye Observed Through an Ophthalmoscope

numerous in the fovea and diminish towards the periphery. The rods which are entirely lacking in the foveal center slowly increase in number to a maximum at about 15-20 deg. from the fovea and then diminish in number per unit area towards the periphery. The receptors of the retina contain the visual pigments which play an important role in the transduction of light into nervous impulses.

Figure 4 is a horizontal section through the eye and the brain showing the conducting pathways: the optic nerve, the chiasma, which is a bifurcation of the optic nerve into two branches, one conducting to the same side, the other crossing over to the other side of the brain. Thus the pathways beyond the chiasma, the optic tracts and optic radiations send messages from the two corresponding halves of the two retinas to the visual center in the occipital cortex of one side of the brain.

An internal or intrinsic eye muscle system adjusts the shape of the crystalline lens (and thus the dioptric power of the eye) enabling us to see clearly at different distances. This adjustment, called accommodation, requires some time. When one changes gaze from far to near, the process of accommodation requires about 0.5 sec and when accommodating from near to far, about 0.43 sec. This accommodative adjustment becomes slower in persons of 40 years of age and older. The nearest distance to which the eyes can adjust moves out from less than 8 cm at the age of 10, to about 80 cm or farther in a 70 year old person. A person 60 years old with otherwise healthy eyes cannot focus at about 50 - 70 cm distance, without corrective glasses. He should wear bifocals (or trifocals), with a lower portion for reading at short distances and an upper portion for distance vision. The larger depth of focus in old persons due to the smaller pupil compensates, to some extent, for this presbyopia or deficiency in near accommodation. When there is a lack of fixational objects, the crystalline lens assumes a position that causes a nearsightedness known as night myopia or empty field myopia.

The intrinsic eye muscle system in the iris regulates the pupil size. This is a compensatory mechanism to keep retinal illumination at an optimum. The pupil is narrow in bright illumination and large in dim illumination. Pupillary contraction can be considered a protective measure against excessive light, but the protection is not always sufficient. A protection by the pupil alone may not be fast enough. With an intense light stimulus, a pupillary contraction is accomplished in 1.0 sec. Fortunately, a lid closure occurs in about 60 msec.

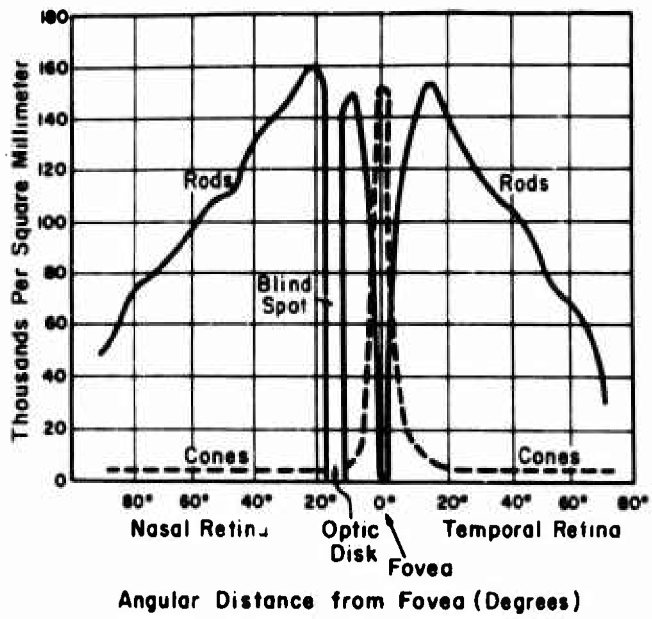

Figure 3. Distribution of Rods and Cones in the Human Retina

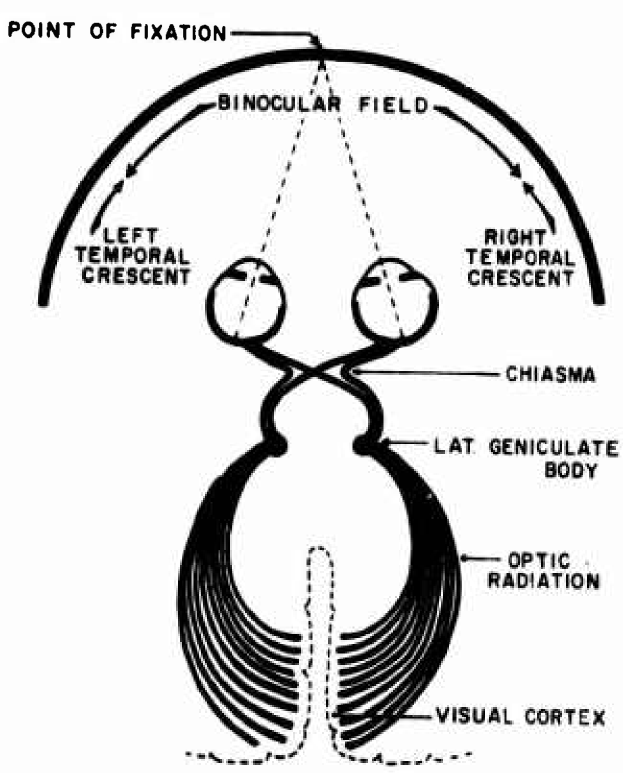

Figure 4. The Pathway from Visual Field to Cortex

The pupil diameter varies from the extremes of 2 mm to nearly 8 mm in diameter. The pupil stays narrower in old than in young persons. This difference is significant in dim illumination -- the pupil of a 60 year old person is 1 1/2 mm (in diameter) smaller at night than that of a person 15 years of age. This, in addition to some cloudiness of the media, accounts for the fact that older people require higher contrasts in order to see in dim illumination.

The movements of the eyeball are carried out by three pairs of extrinsic eye muscles. Normally, both eyes move together. Eye movements in which the angle between the two primary lines of sight does not change, are termed versions. The primary line of sight connects the fovea, the apparent entrance pupil of the eye and the fixation point. When the angle changes, the movements are vergences: a convergence of a divergence. Fixational scanning movements can be both versions and vergences. Fixation of one point usually lasts not longer than 0.5 - 2 sec., and then the eyes move to another point of attention in a jerky, so-called saccadic movement. These interfixational movements are, generally, very precise and very rapid. When the eyes are following a uniformly moving object, for instance, a car approaching from a crossroad, both jerky saccadic and smooth pursuit movements occur.

Horizontal movements are slightly faster than vertical movements and rotatory eye movements are more difficult. When changing fixation from a distant point to a near point the eyes converge, which is an involuntary reaction in the interest of binocular single vision. The amount of convergence is greater, when the eyes look down, than when the near object is straight ahead. Convergence movements are slower than versional movements. One can increase convergence faster than one can relax convergence or diverge the eyes. The near point of convergence (NPC), the nearest distance at which binocular vision can be maintained without doubling, is at about 8 cm. It does not change with age. A disturbance of the eye muscle balance can cause double vision, called diplopia.

As soon as a message is transmitted to the brain, an involuntary evaluation of this message occurs in the consciousness which eventually leads to a perception. The perception occurs as the result of all sensory mechanisms working in unison, but for purposes of simplification they are discussed separately. For instance, in central vision, we detect that there is something on the ground, because it is lighter or

darker than the ground. This information is mediated by our contrast sensitivity. Contrast sensitivity depends on the adjustment of the sensitivity of our visual organ, which is known as adaptation. We may identify the object correctly by recognizing its details. This ability of our eye depends on the contrast, on the background luminance, on the receptor mosaic of the retina, on psychological factors (such as interpretive ability) and is known as visual acuity. We may further recognize the color, the distance of the object, whether or not it is moving, and if so, its speed."

b. Sensory Mechanisms

"A description of the sensory mechanisms of the visual organ usually starts with an explanation of the physical properties of light, which is the adequate stimulus for the eye, and a definition of the light units with which ordnance engineers should be familiar. It may be emphasized that light is an entirely subjective response to radiation and that brightness is not identical with luminance. Brightness is a psychological attribute of sensation by which we are aware of differences in luminance. A surface which appears twice as bright as another surface may have a luminance which is 10 times higher than the other. Brightness changes approximately logarithmically, while luminance changes arithmetrically.

The process of adjustment of the eye sensitivity to the luminance of the area which the person is viewing, is known as adaptation. During the process of adaptation, the sensitivity of the eye changes, and finally, reaches a more or less constant level of sensitivity. We then say that the eye has "adapted" to the luminance.

In accordance with characteristic differences in the responses of our visual organ, it is appropriate to distinguish three stages of vision dependent upon the luminance to which the eye is adapted:

(1) Photopic vision or daytime vision. This refers to the stage of, essentially, pure cone activity, from 1 mL* up to the limit of comfortable vision, which may not be higher than 10,000 mL. Peripherally, the lower limit is about 1 mL.

(2) Mesopic vision or twilight vision. This refers to the intermediate stage in which the activities of both retinal

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* 1 mL = 1 millilambert

receptor types overlap. It reaches from the lower limit of the photopic vision down to approximately .0003 mL.

(3) Scotopic vision or night vision. This reflects the stage of pure rod vision, from the mesopic range on down to the lowest threshold of vision (approximately .000001 mL).

Daytime seeing is done in photopic vision. At sunset, there may exist mesopic levels in shadowy areas and for a while after sunset, seeing is done in the upper mesopic level of vision. Night seeing occurs at the lower level of mesopic vision. The environment of the observed usually provides a nonuniform background. His eye sensitivity is then determined by the average of the different luminances which his eyes are scanning.

Luminances are measured by luminometers. At the present time, one of the most precise is the Pritchard Spectrophotometer which enables one to measure luminances of surfaces of any size down to 2 min of arc in diameter.

Light or dark adaptation is measured by adaptometers, of which the most elaborate is the Goldmann-Weekers adaptometer. To measure dark adaptation, first, an initial standard sensitivity level is created by looking for several minutes at a bright surface of standard luminance. After this illumination is turned off, the threshold luminance is determined at certain time intervals in total darkness (that is, the minimal amount of luminance for detecting a target) -- the less luminous flux required to just perceive the target, the higher the light sensitivity. Results of measurements of adaptation to different levels (low) of background luminances are shown in Fig. 5.(2) One can distinguish, first, a sudden increase in sensitivity as soon as the pre-adapting light is turned off. This sudden increase is known as alpha-adaptation.(3) It is followed by a slower beta-adaptation process. The background luminance for the upper curve is in the range of photopic vision, that of the second curve is in mesopic vision. The terminal sensitivity of these two levels is reached in less than 5 minutes. On the lower three curves, which are in the scotopic range, the final threshold is reached after 15 minutes. The kink in the lower three curves marks the time at which the cones stop participating at these low luminances. Aging persons have higher luminance thresholds than young persons, since they demand more light in order to see at low illuminations.

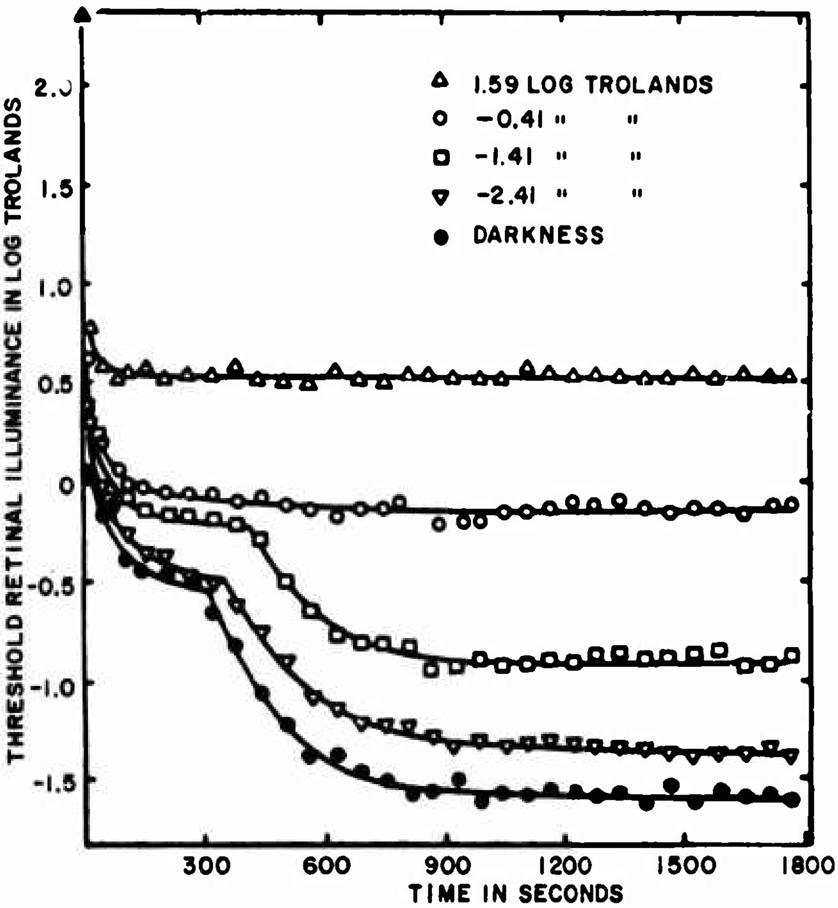

Figure 5. Adaptation of Backgrounds of Different Luminances. Targets Brighter than Background. Retinal Region 8 deg from the Fovea.

When testing dark adaptation with targets darker than the background, the terminal sensitivity level is reached later than when testing with targets lighter than the background. At this terminal level, the luminance of the just visible darker target is as much below the level of the background as the target lighter than the background is above it. (See Fig. 6.)

When one comes out of a brightly illuminated room into the dark night, the eye requires time to adjust to the darkness. The brightness of the room determines the amount of time required for such adjustment. When one comes out of a dark room into a brightly illuminated area, as from a dark tunnel into sunlight, one cannot orient oneself very well at

first, but within 30-60 sec one is able to distinguish details. Thus, light adaptation is a short process. The light-adapted eye is not very sensitive to light, and thus, the luminance difference necessary to make a target visible on a bright background is fairly large. At the onset of the light adaptation process, we again find an alpha-adaptation phase, that is, a suddent drop in sensitivity in fractions of a second. During the following light adaptation, the sensitivity improves to some extent, but remains far below that of the dark-adapted eye. This first overshooting is probably a safety mechanism against sudden illuminations.

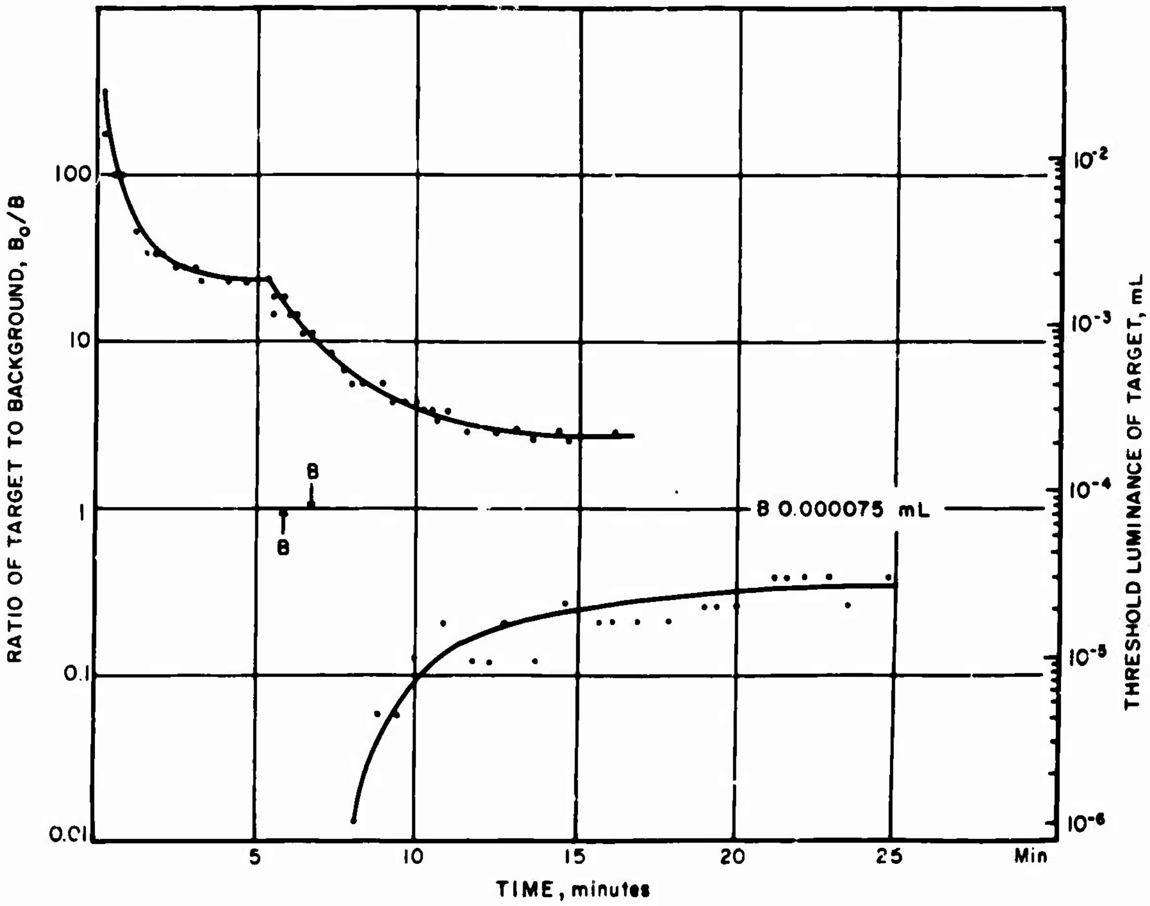

Figure 6. Adaptation to a Target Brighter Than the Background (upper curve) and a Target Darker Than the Background (lower curve). Abscissa: Time After Extinction of the Light Source for Pre-adaptation. Ordinate: Threshold Luminance of Target in mL, also ratio of Target to Background Luminance.

The obtained terminal sensitivity is not uniformly distributed over the whole retina. In photopic and mesopic vision, the highest sensitivity to light is found at the fovea, but in scotopic vision, the highest light sensitivity is found in an area 15-20 deg from the fovea. Since fixation is done foveally, the adaptation of the fovea is of prime importance. Foveal adaptation is, largely, dependent upon the luminance of that part of the visual field which is imaged at the fovea. The entire surrounding contributes less than 10 percent to the total effect.(4) A glare source at an angle of 7 deg does not appreciably affect foveal sensitivity. (5)"

c. Contrast Sensitivity

"To a great extent, the recognition of objects is based on a recognition of brightness differences. At night, an object may appear as a darker area against a campfire or against the horizon. It may also appear as a brighter area when illuminated against the dark surroundings.

Contrast is a photometrically measurable luminance difference of two areas. The ability to recognize differences in luminance is contrast sensitivity. The barely recognizable luminance difference of two areas is the differential threshold. It changes during adaptation and serves to measure the progress of adaptation. Contrast sensitivity is usually measured with the eyes perfectly adapted to the background luminance, for instance, to show the effect of a parameter. The higher the background luminance, the more the light that must be added in order to make a target visible, thus the differential threshold is larger. The light-adapted eye is less sensitive to light, when one considers the amount that should be added in order to see the target. The ratio of the differential threshold to the background luminance is much smaller in the light-adapted, than in the dark-adapted eye. Hence, the contrast sensitivity of the light-adapted eye is higher than that of the dark-adapted eye.

It is customary to express contrast by the formula,

$$C = \frac{B_o - B}{B} \qquad (1)$$

where B = luminance of the background

B_o = luminance of the object

When B_o is higher than B, the contrast is positive and may vary between 0 and ∞. When B_o is lower than B, the contrast is negative and may change from 0 to -1. The more general expression for threshold contrast is

$$C_t = \frac{\pm \Delta B}{B} \qquad (2)$$

Various authors define contrast differently.

There is much information about the parameters affecting the threshold contrast on a background of uniform luminance, with targets brighter than the background. The most widely known data are the so-called Tiffany data published by Blackwell. (6) Figure 7 shows some of Blackwell's curves extended by Taylor beyond the 6 deg circle which was the largest used by Blackwell. (7) The largest possible target may be represented by one side of a split field. The curves show the dependence of the threshold contrast ($+ \Delta B/B$) on the background luminance and on the target size. The threshold contrast diminishes with increasing background luminance and with increasing diameter of the target and, finally, becomes a constant. The vertical ends of the curves show that the contrasts here obey the Weber-Fechner's law according to which the liminal luminance increment is a constant fraction of the luminance of the background, namely 1 to 2 percent. This law is valid over a restricted luminance range only, namely about 10 to 1000 mL.

With luminances higher than those shown in Figure 7, the threshold contrast increases to some extent, probably because of the additional stray light produced in the eye with the background serving as the glare source (Figure 8). Blackwell has also measured threshold contrasts on targets darker than the background. (6) He found that they differed little from objects brighter than the background (except at low adaptation luminances and for large stimuli). Similar results are reported by Aulhorn. (8) Figure 9 (after Blackwell) demonstrates the effect of the exposure time together with the effect of the target size on threshold contrast. (9)

Figure 10 (after Aulhorn and Harms) shows the dependence of the differential threshold for a 10 min. circular target (exposure time at least 1 sec) on the retinal region. (10) The results are presented graphically using only the horizontal meridian of the visual field of the right eye. The differential thresholds are represented on the ordinate,

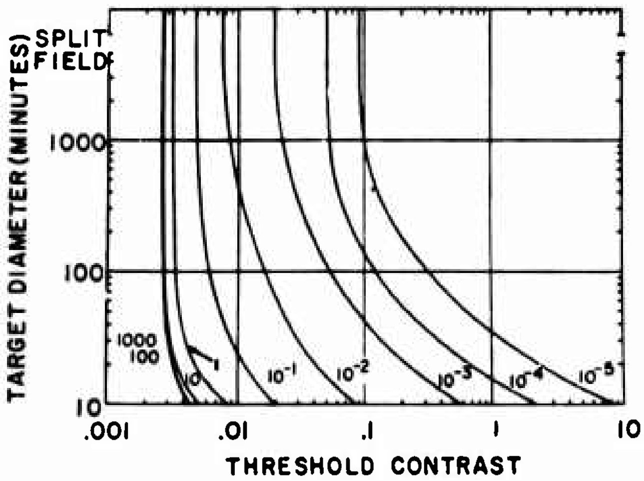

Figure 7. Threshold Contrast as a Function of the Diameter of a Uniform Circular Target

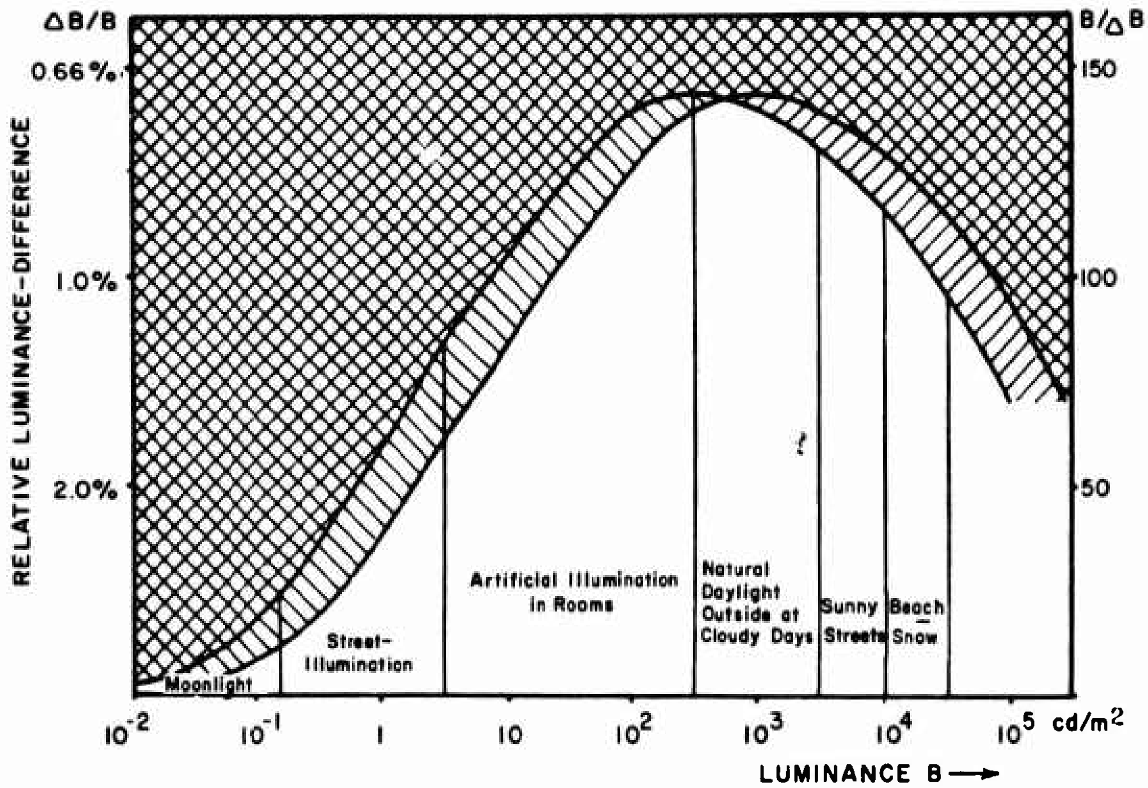

Figure 8. Threshold Contrasts at Different Luminance Levels

in reverse order to express the trend of the eye sensitivity which is reciprocal to the threshold stimulus. Highest light sensitivity is found, at background luminance zero, at a peripheral area of about 15-20 deg from the fovea. The central area is insensitive to scotopic levels of luminance, thus causing a "physiological" scotoma or nonseeing area. At the lower limit of mesopic vision, that is at an adaptation luminance of 0.001 mL, the sensitivity of the retina is most uniform, showing a kind of plateau of the differential threshold. In photopic vision, the trend is just opposite to that in scotopic vision. Now the foveal area has the highest light sensitivity and the sensitivity decreases appreciably toward the periphery. One can deduce from these findings that in mesopic vision, with its almost uniform overall retinal sensitivity, less scanning need be done to detect a dimly illuminated target than at higher luminance levels. Fortunately, in photopic vision, eye movements are most precise.

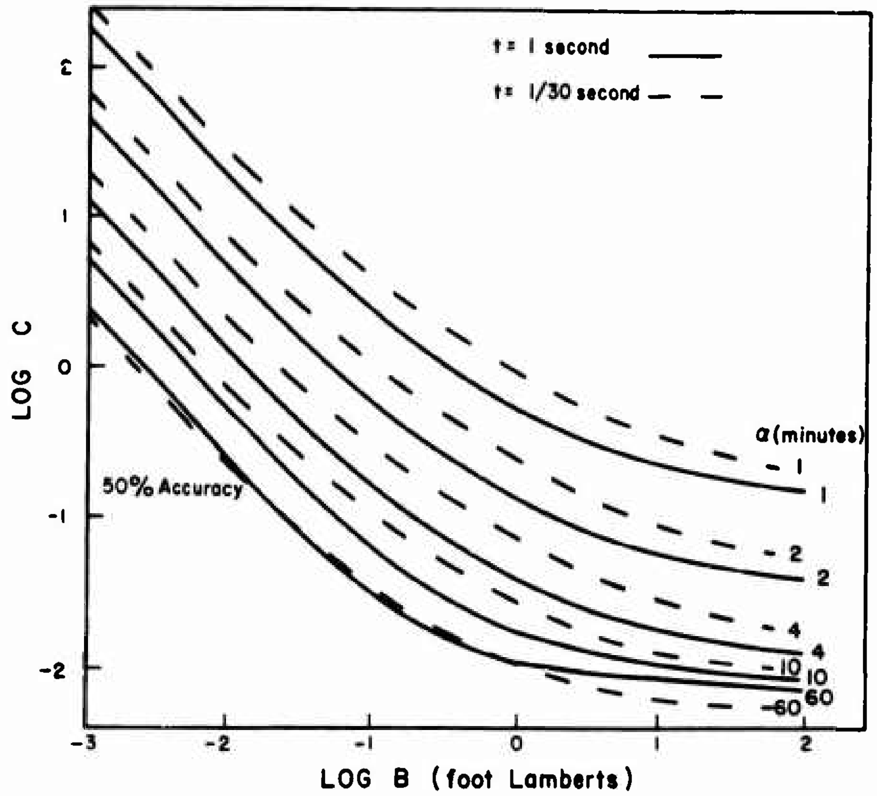

Figure 9. Effect of Exposure Time, in Seconds, and Target Subtense in Minutes, on Threshold Contrast (log C) on Different Background Luminances (log B ft-L)

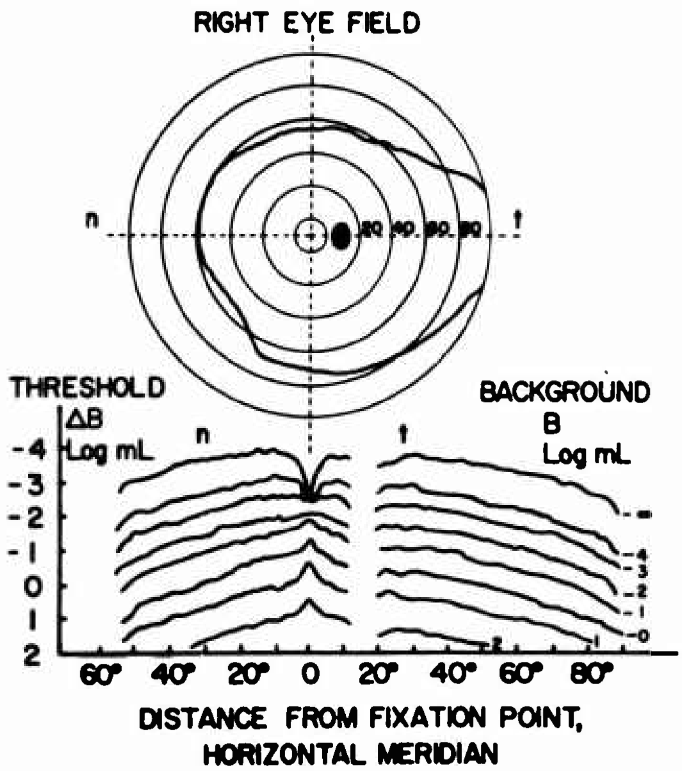

Figure 10. Retinal Sensitivity in the Horizontal Meridian at Eight Background Luminances

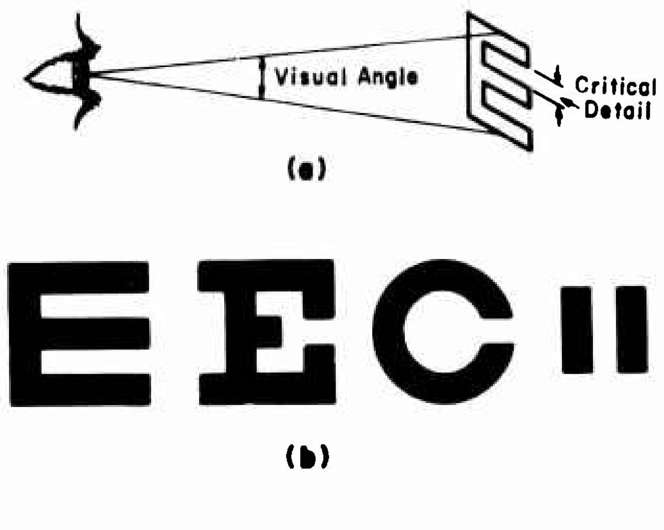

Figure 11. Visual Angle Subtended by the Letter of a Visual Acuity Chart and Various Test Type Letters

The shape of a target does not matter as long as the object is so small that it stimulates only one receptor unit. Such a unit may comprise several cones or rods. The dimmer the illumination, the more photoreceptors work as a unit, up to an area of 8 min diameter in dark adaptation. Elongated objects would have threshold contrasts different from objects of equal length and width because they stimulate retinal areas which differ in slope of sensitivity. (8) (See Figure 10.) Physiological mechanisms going on at the border of the target and the background are responsible for the differentiation of the target. These border mechanisms have been extensively studied in the last decades. Large fluctuations of the background luminance or the "luminance noise" affect the threshold contrasts. (11) When looking at great distances, atmospheric scattering and absorption would change the physical characteristics of the background and the target. A neutral density filter in front of the eyes does not change the contrast, but decreases the general luminance level and thus impairs viewing.

Several devices have been developed to solve practical visibility problems, for example, the Luckiesh and Moss, the Finch visibility meter and Blackwell's visual task evaluator. (12) Since we are usually not exposed to threshold luminance levels in practical situations, Blackwell has suggested using a "field factor" of the magnitude of at least 15 in order to convert his data to suprathreshold levels of seeing.

Contrast sensitivity enables us to detect objects. The identification of an object is accomplished by a higher visual function, namely visual acuity. Be definition, visual acuity is the ability of the eye to resolve small details. Static visual acuity occurs when object and observer are stationary.

The distinction of a point is a function of contrast sensitivity. An infinitesimally small light point can become visible with sufficient intensity, therefore, there is no lower limit to its size. The upper limit of a point is defined by the receptor group in the retina that acts as one unit. In the dark-adapted eye such a unit may be 8 min of arc in diameter; in the light-adapted eye, up to 0.5 min of arc. In order to be perceived, a point darker than the background must have a certain dimension which depends on the stage of vision. This minimum, against a bright background of 1000 mL, has been established by Hecht, Ross and Muller to be about 20 sec of arc. (13) On darker backgrounds, this limit was found to be larger.

The perception of a line is also a function of contrast sensitivity. There is no lower limit to the width of a bright line, since its intensity can be increased infinitesimally. A blackline must cast a shadow (non-stimulated area) on the retina, thus producing a sufficient luminance difference in order to be perceived. Hecht and Mintz found that the minimal resolvable blackline had a width of 0. 5 sec of arc, but that it had to be of at least 1 deg in length in order to be seen. (14)

The detection of two light points close together as a brightness difference from the background, is a function of contrast sensitivity, but the distinction that they are two points separated by a dark interspace is a function of visual acuity. This minimum separation can be as low as 15 sec of arc. (15) A special case is the recognition of a break in a vertical or horizontal line (Vernier acuity). Under favorable conditions, a break of 2 sec of arc can be recognized. This "aligning power" of the eye depends to some extent on the length of the line."

d. Visual Acuity

"The clinical threshold visual acuity is usually given as 1 min of arc, although many young persons can do better than that. Clinical testing of visual acuity is based on a size of black letters or numbers on a well illuminated white background. Snellen letters, and those improved by Sloan and Landolt C's are widely used. (16) (Figure 11) Visual acuity testing is, generally, given near and at distance in foveal vision. If a person, from a standard distance, resolves a letter subtending 5 min of arc, of which each interspace or each width of letter bars (critical detail) subtends 1 min of arc, this person has a (threshold) visual acuity of 1. 0. If he can resolve only letters, the critical details of which subtend 8 min of arc, he has 1/8 visual acuity. Thus, visual acuity is expressed by the reciprocal of the minutes of subtense of resolvable critical details. It is also expressed by a ratio of distances. A person has 20/20 vision, when he can read letters that subtend 5 min of arc at a distance of 20 ft. Astronaut Cooper has a visual acuity of 20/12, thus he can resolve letters from 20 ft that subtend 5 min at 12 ft. This accounts for his amazing visual performance in outer space.

Visual acuity is a complex function depending on a great number of variables. The sharper the focus of the retinal image, the better the visual acuity. The pupil participates in forming a sharp retinal image, thus visual acuity depends on the pupil size.

With increasing illumination, visual acuity increases up to a luminance of the background of about 10 mL and then remains constant despite increasing illumination. This is explained by the limit for resolution set by the fineness of the retinal mosaic. One row of cones must be less stimulated than its neighboring row for the perception of a border. The width of a cone is found equal to 12 sec and more. With luminances above about 30 mL it is advisable for maximal visual acuity to brightly illuminate the immediate target surroundings (0. 5 deg) and to keep the larger surroundings slightly below this value. (17) The eyes of older persons require more illumination for a visual acuity task than those of young people.

When one uses two bright bars of sufficient width on a black background, visual acuity shows an increase with an increase of their intensity. However, for thin bars, there is a delay and even a decline of visual acuity with increasing intensity, which has been explained by Fry and Cobb as inhibiting border mechanisms. (18)

Visual acuity increases with increasing contrast of the target. This problem has been recently more thoroughly explored by Aulhorn.(8) The visual acuity task was the distinction of a square from a circle of equal area at variable sizes. A critical detail of the square served to compute visual acuity. The contrast sensitivity was the same for both patterns. They were detectable as ill-defined spots on equal luminance difference, at all luminance levels of the background. Figure 12 shows the result for targets brighter than the background, and Figure 13 shows the results for targets darker than the background. The luminance of the background is shown at the end of each curve, with the visual acuity on the ordinate, and on the abscissa the luminance difference of the target which is required to distinguish a special size square from the circle of equal area. The curves permit one to establish visual acuity for a target of given luminance on a background of a given luminance, since the data is in agreement with the clinical testing of Snellen letters. After obtaining the subtense of the critical detail from the curve, the distance can be deduced at which a target may be identified. Figure 12 also shows that a plateau, finally, is reached beyond which an increase in luminance does not yield any better visual acuity than at the maximum. With a target darker than the background, a limit is set by the impossibility of subtracting from the background more than its own luminance. The problem frequently arises as to whether black letters on a white background or white letters on black are preferable. The data in the literature is controversial, which may imply that there is probably no

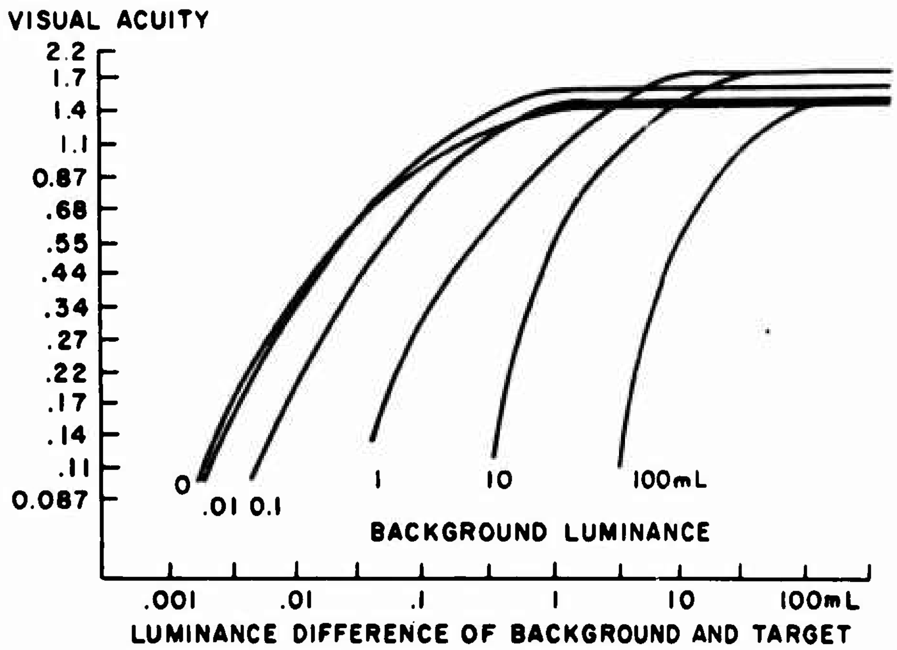

Figure 12. Visual Acuity on Targets Brighter Than the Background

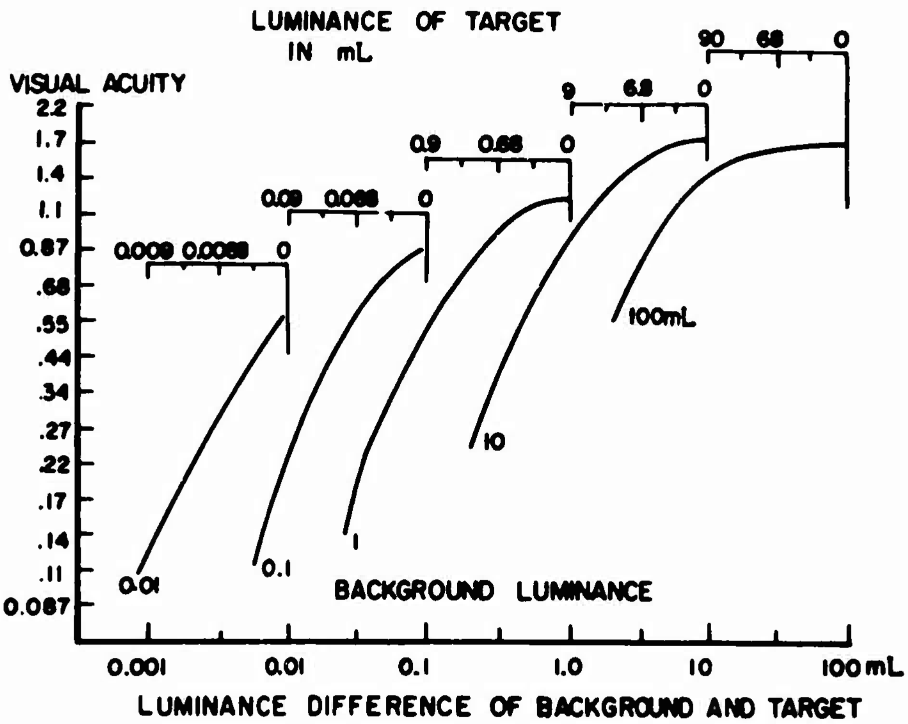

Figure 13. Visual Acuity on Targets Darker Than the Background

striking difference. From Aulhorn's data, it is obvious that the threshold luminance differences required for targets darker than the background are slightly smaller.

Visual acuity depends on the retinal region. In photopic and in mesopic vision, visual acuity is keenest in the fovea (Figure 14). In scotopic vision, the best visual acuity is found in a parafoveal area of 1-4 deg from the fovea.

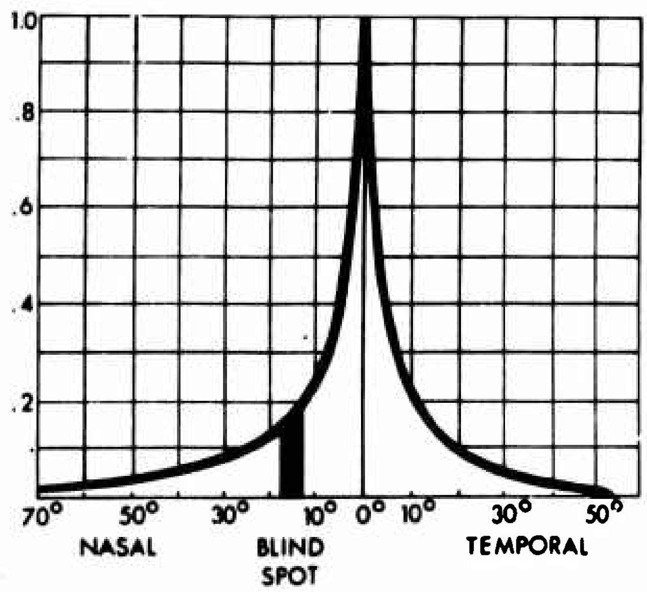

Figure 14. Regional Variation of Visual Acuity; Abscissa, Retinal Region; Ordinate, Relative Visual Acuity

An optimal exposure time for a visual acuity task is 0.5-1 sec.(19)

Our vision is better adapted to perceive straight borders than wavy or curved borders. (20) Figure 15 shows the effect of configuration on visual acuity on a constant background luminance of 1 mL. The three compared shapes are equal in area and their threshold constants are equal at all sizes (upper curve). The identification of their shapes requires different contrasts. The diamond is more easily resolved than the other two shapes. The achieved visual acuity should be computed from the reciprocals of the diameter of a circle of equal area with the pattern in question. The higher the number of edges in a pattern, the more contrast required to identify its shape.

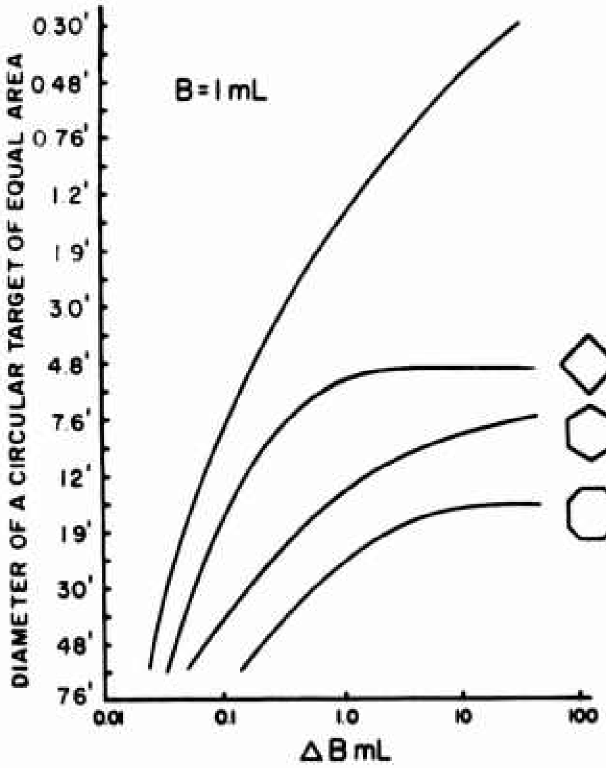

Figure 15. Differential Threshold for Detection (upper curve) and for Shape Identification of Three Configurations. Luminance of Background 1 mL; Sizes are Indicated on the Ordinate by the Diameter of a Circle of Equal Area with the Configuration.

Visual acuity depends on the interpretative functions of the brain. It can to some extent be compensated by the psychical attitude, for instance, the recognition of a familiar form which is not clearly seen."

e. Glare

"The vision of an observer can be suddenly disturbed by glare, for instance, at night by the headlamps of an oncoming car, or in daytime, when coming from a dimly illuminated tunnel into a sunlit landscape. When evaluating the subjective impression of bearable or unbearable glare, we speak of discomfort glare; when evaluating glare by its impairing effect on the visual performance, we speak of disability glare. All disability glare is also discomfort glare, but glare can

cause discomfort without impairing visual functions. The computations regarding glare effects involve foveal vision. A glare source can be specified by its luminous quantity, the solid angle subtended at the eye, its distance and its location in the three-dimensional space (Figure 16). The glare angle θ is the angle between the primary line of sight of the observer and the direction of the glare source.

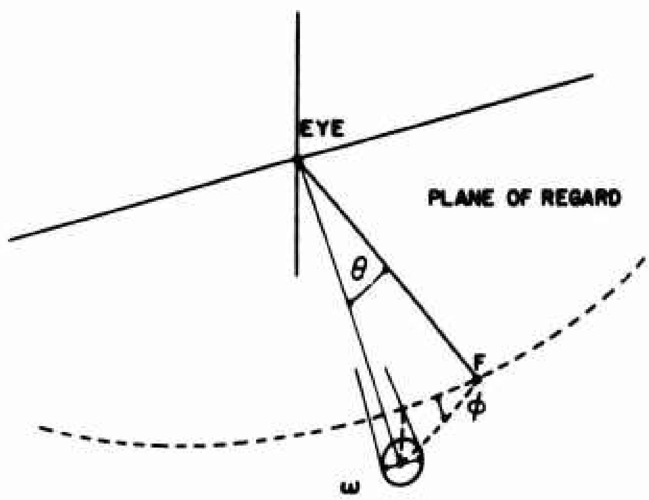

Figure 16. Specification of a Glare Source in Physical Space

In respect to the discomfort caused by a glare source, a borderline comfort-discomfort value can be established by averaging the luminances which, for a number of subjects, have been designated as barely tolerable and those barely intolerable. Discomfort glare is a function of the luminance and of the size of the source (in steradians) and inversely related to the glare angle and the luminance of the surrounding field. In general, discomfort is experienced when the difference between the luminance of the working area and the glare source is larger than 2 log units. It is less disturbing when the glare source is above the plane of regard, because of the protection by the upper lid. (21) A yellow light source causes less discomfort than a blue source of the same intensity, although the disabling effect is the same.

The impairment of visual functions caused by disability glare can occur as a simultaneous effect while the glare source is on, or as an

after-effect, when the glare source is no longer visible. A glare source causes a veil superimposed over the retina which is most intense in the immediate vicinity of its own image. The latter represents an ill-defined blot. The veil gradually decreases with increasing distance from this image (veiling glare). The origin of this veil is stray light caused within the eye by the optical media, the cornea, the crystalline lens and the retina. The latter acts as an integrating sphere. In and around the retinal image of the glare source, the sensitivity may be so reduced that a blind area may result, thus causing a scotoma in the visual field (scotomatous glare). For instance, assuming a luminance of 1 mL to which the observer is adapted and a target brighter than the background of luminance of 1.02 mL (just detectable), the threshold contrast would be about 0.02. A veiling luminance of 10 mL from a glare source increases the adaptation luminance to 11 mL and the luminance of the target to 11.02 mL. The contrast is now equal to 0.002. Since the threshold contrast at 11 mL is the same as before, namely 0.02, the target now cannot be seen.

Thus a veiling glare adds to the luminances present, but always diminishes contrast and thus, the discrimination of details. As we already know from the light adaptation process, when the level of illumination suddenly increases there is first a sudden drop of sensitivity for some fractions of a second. Schouten and Ornstein established that this inhibitory effect of a glare source occurs in the first 100 msec, and is followed by a more or less constant level of impaired sensitivity, during which measurements of the veiling glare B_V can be carried out conveniently.(3) Such measurements lead to simple expressions, of which Holladay's formula is probably the most widely known.(22) In its generalized form the formula is

$$B_V = \frac{k\,E}{\theta^n} \qquad (3)$$

E equals illuminance caused by the glare source at the eye which can be measured directly by an illuminance meter or computed, when the intensity or the luminance of the glare source is known. The constant k is equal to 9.2 when E is expressed in lumens per square meter and B_V in candles per square meter. It is 28.9 when E is in footcandles and B_V in footlamberts. The angle θ is the glare angle and its exponent n equals approximately 2.0. This formula for the veiling glare has been established for glare angles of 2.5-25 deg. For smaller glare angles, Fry established the expression:(23)

$$B_v = \frac{9.2 \; E \cos\theta}{\theta \; (1.5 + \theta)} \quad (4)$$

Thus, the veiling glare depends on the illuminance produced at the eye by the glare source and on the glare angle, but its size, for example, the solid angle subtended at the eye, as long as it is not on the primary line of sight, is not a factor in producing disability glare. With angles larger than 2 deg from the nearest point of the edge of its image, the shape of the glare source can be neglected. (24)

Aulhorn found a maximal glaring effect, when the distance of the two sources was about 50 meters, which occurred on a glare angle of 3-5 deg. (5) The veiling effect became negligible at glare angles about 7 deg. Holladay found that veiling glare remained the same, when the location of the glare source was changed in a circumferential manner around the line of fixation without changing the glare angle. (22)

Hartmann has computed the just tolerable illuminances at the eye, before disability sets in, for different glare angles and different background luminances to which the eyes were adapted (See Figure 17). (25) The illumances plotted against the glare angle for each background luminance results in a straight line (on log/log plot), thus showing an exponential relationship. The expressions E/θ^n, which is Holladay's formula, was a constant for any given background luminance. In practical situations, the illuminances to be avoided may be different from the calculated values, because of unexpected meteorological factors, straylight from sources other than the eye, the variable luminance of the background and the constant shift of the eyes which necessarily changes the glare angle. In case of several glare sources, the effect can be predicted by summating the increments of straylight falling on the fovea from the individual sources.

Veiling glare can be measured by the Fry glare lens attachment placed in front of the objective lens of the Pritchard telephotometer. (26) This lens measures the disability glare from the entire visual field.

The resistance to glare, that is the ability to retain some vision regardless of the presence of a glare source, varies from subject to subject. In the eyes of old people the amount of glare produced is higher, and thus, the glare resistance is lower, because of a higher scattering ability of the eye media.

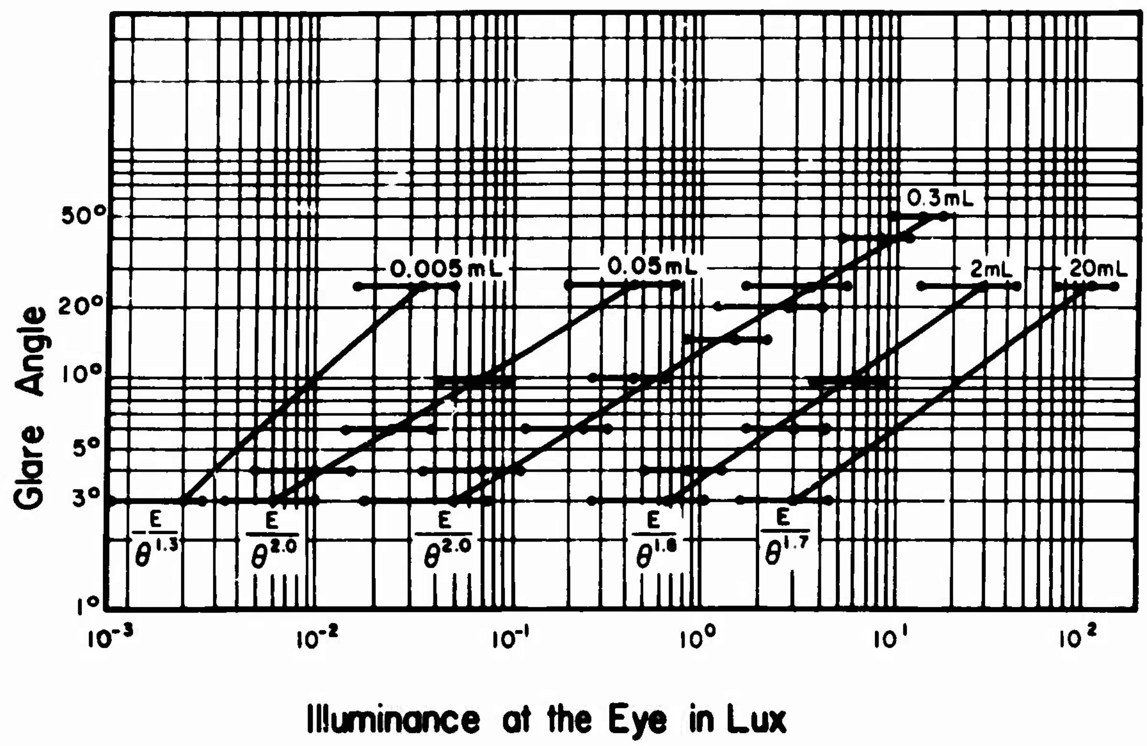

Figure 17. Just Tolerable Illuminance at the Eye (abscissa) as a Function of Different Glare Angles (ordinate): On Top of Each Curve and Adaptation Luminance in mL, on the Bottom, Holladay's Exponent

After a glare source ceases to affect the eye, an after-effect manifests itself as an after-image. Positive and negative after-images may alternate. The positive after-images are equal in brightness to the area that induced the after-image. Negative after-images display a reverse brightness relationship. The after-images are interrupted by short intervals during which some details may be visible. The recovery time of sensitivity after a glare depends on the luminance, on the duration and on the position of the glaring light. For practical purposes, recovery can be assumed completed not when the after-images have disappeared, but when the same details can be seen which were seen before the glare source appeared. Figure 18 demonstrates the dependence of the recovery time on luminance and duration (log mL-sec) of a glare source and on the luminance of the display used. (27) In comparison to the long duration of adaptation to dim luminances, the recovery after a short glare is relatively rapid. According to Kinney

and Connors the veiling glare produced by oncoming headlights lies within the range of 0.3-3000 ft-L. (28) This resulted in the same recovery time (of 40 sec) on a glare angle 0 deg when the fovea was exposed to 3000 ft-L for 3 sec or to 300 ft-L for 30 sec. Exposures to 100 ft-L for 1 sec seemed to have little effect on the dark-adapted fovea. In aging eyes, the recovery time is prolonged because of the larger amount of glare produced."

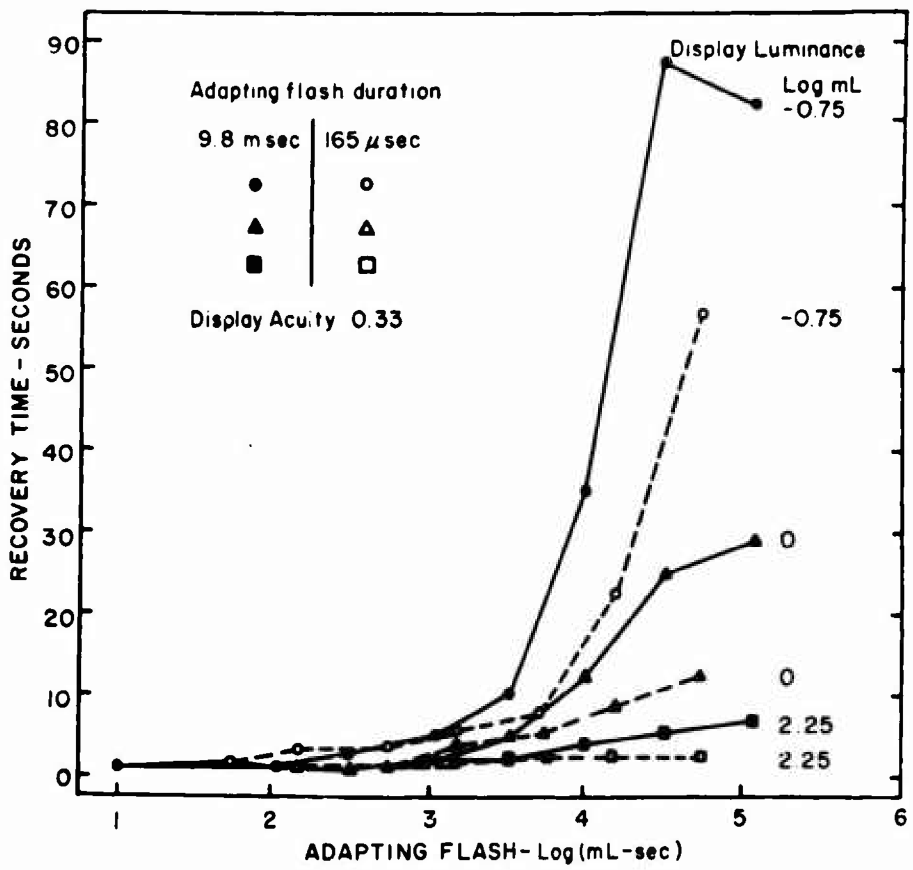

Figure 18. Recovery Time After Glare

f. Response Time

"There is a time elapse between the onset of a stimulus and the onset of its perception, the perceptual latency time (PLT) (Figure 19). In the fovea, this time ranges from 35 msec for an intense stimulus,

and up to 300 msec for a weak stimulus. There is a reciprocal relationship between the log of the intensity of the stimulus and the PLT at all stages of vision, but the PLT can never be abolished entirely. The shortest latency time is found in the fovea at photopic and mesopic levels of vision. In scotopic vision, the shortest PLT is found 15-20 deg peripherally, yet the perception does not approach the rapidity found in photopic vision. Unequal illumination of both eyes may cause a difference in perceptual latency between the two eyes, and thus produce distortions in the apparent paths of moving objects (discussed later). The PLT decreases with increasing size of the target.

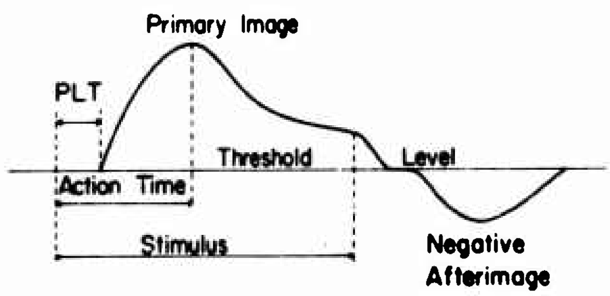

Figure 19. Time Factors in Viewing a Stimulus of Medium Intensity and Duration

The PLT is followed by a sensation known as a "primary image" which reaches an intensity maximum within 100-200 msec, and then gradually drops to a sustained level. After the stimulus has ceased, the primary image continues for a short time before it disappears, and then is followed by a periodicity of after-images which depend on intensity, hue and duration of the initiating stimulus. After a stimulus of medium brightness and of several seconds duration, a longer lasting negative after-image is easily perceived. After-images can be noticed in the recovery period after glare. In everyday seeing there is not much opportunity for developing after-images because the gaze is constantly shifting."

g. Intermittency Effects

"A light may become more conspicuous when presenting it as an intermittent light. At a frequency of 8-12 flashes per second the

flash appears brighter than when the same light is seen as a steady light (Bruecke-Bartley effect). This is most effective at a luminance of the steady light of 60-100 cd/ft^2* and at a light/dark distribution in a cycle such that the light is on for one third of the time. (29) The light phase duration on a frequency of 10 cps equals 30 msec which is about its action time (Figure 19). Strughold observed that a light of low intermittance of 3 to 6 cycles per sec produces a discomfort. (30) This information may be kept in mind when designing flashing light signals."

h. Perception of Motion

"Perception of motion is the ability to perceive a change in location of objects in time, and is actually a special case of direction and distance perception. This movement may occur in a plane frontoparallel** to the observer, in a horizontal, vertical, oblique or rotatory direction, or it may be a motion in depth, the object thus approaching or receding.

Perception of motion involves alterations of the retinal images, which may occur:

1. When the eyes are fixed and when an object is displaced in a stationary environment, the retinal image of the object is displaced.

2. When the eyes are following a moving object, the image of the target remains fixed but that of the environment is changing.

3. When the eyes are stationary and the retinal image of an object grows or shrinks in size and may also change in shape; the impression is that of an object moving toward or away from one in a stable environment.

4. When the eyes are passively moved by one's finger, the whole visual field appears to move.

*cd/ft^2 = 1 candela per square foot = 3.382 mL.

**A frontoparallel plane is a plane parallel to the frontal plane of the observer. A frontal plane is a plane through two points of reference representing the two eyes, for example, the two entrance pupils and is perpendicular to the plane of regard which contains the two primary lines of sight and the fixation point.

Thus, perception of motion is given by a retinal impression, but the nature of the perception depends on associations in the higher brain centers.

One can specify a movement by the speed, that is the distance traveled per unit time, and by the minimal displacement of an object required to perceive its motion. In case of a motion in a frontoparallel plane, the data can be expressed in angular values (degrees/sec, and the like) subtended at a pivot point. In case of great distances, this point would be the head of the observer.

The minimal perceptible speed was determined by Aubert to be 1-2 min of arc per sec, (in the presence of stationary reference objects and when fixating the target). (31) In the absence of the reference objects, for example, when a light point is moving in dark surroundings, it was 15-30 min. of arc per sec. Basler found a 20 sec threshold of displacement in photopic vision, when there were stationary reference objects in the field. (32) In total darkness, the threshold of displacement for an isolated object was about four times higher. The threshold of displacement depends on the speed of the object. These data add to the understanding of the amazing visual performance of the astronaut Cooper, who was able to distinguish vehicles on Tibetan roads from his spaceship.

The speed of threshold and the threshold of displacement are lower in photopic than in scotopic vision. The higher the contrast of the moving object, the lower the threshold of motion will be. The perception of motion is more accurate if "sufficient" exposure time is allowed. Perception of motion (speed and displacement) is better in the fovea than in the periphery. (33) Nevertheless, one can say that recording of displacements in space is the most fundamental and valuable function of the peripheral retina. Stationary objects of low contrast disappear in peripheral vision fairly rapidly due to local adaptation, whereas they remain visible when in motion (provided that motion is above the threshold value). A motion may be overestimated when perceived peripherally.

There are contradictory statements about whether the estimation of a velocity is more accurate at low or at high speeds. A low velocity of 0.4 deg per sec was difficult to estimate, whereas a speed of 40 deg per sec was judged more precisely. (34) Gibson devised a motion picture "estimation of velocity test" which enabled the subject to estimate

the location of an airplane moving in a transversal direction, after it had disappeared behind a cloud. (35) The subject was able to extrapolate the target motion with a velocity error of less than 20 percent. Estimates of speed are generally inaccurate.

When observing motion of an object from or toward the observer (motion in depth), there may be no displacement of the retinal image, but only various transformations of its size, contours, shape, and change of interplay of light and shade on the moving object. This perception of motion is an appreciation of distance changing in time, and there are definitely distance cues involved. Up to the present, it has been studied mainly at short distances. Figure 20, after Baker and Steedman, shows that the observation time required to recognize motion in depth decreases with increasing speed. (36)

The resolution ability of the eye, when there is relative motion between the observer and the object has been termed dynamic visual acuity (DVA) by Ludvigh and Miller. (37) Relative motion is present whem the observer is stationary and the object is moving, or the observer is moving and the object is stationary, or the object and the observer are moving.

DVA is usually measured by presenting a moving target, variable in size, a Snellen letter or a Landolt ring, at a constant speed and determining the size that can be resolved. The other possibility would be to keep target size constant and reduce the speed until the target can be identified. The motion may be in a frontoparallel plane or a motion in depth.

DVA is worse than static visual acuity (SVA) when the pursuit eye movements are not capable of holding a steady image of the target on the retina. The image becomes blurred and therefore it contrast decreases. Smooth lateral pursuit eye movements are possible up to a velocity of 30 deg per sec. At higher speeds, the pursuit movements lag increasingly behind the target and must be compensated by frequent saccadic movements. (38) Head movements support DVA.

In experiments with a limited exposure time of 0.4 sec and with the head fixed, Ludvigh and Miller found that visual acuity begins to deteriorate at a speed of 20 deg although not appreciably until 30 deg per sec (Figure 21). (37) Zero acuity (total blur) occurs at about 200 deg/sec. With free head movements and with longer exposure times,

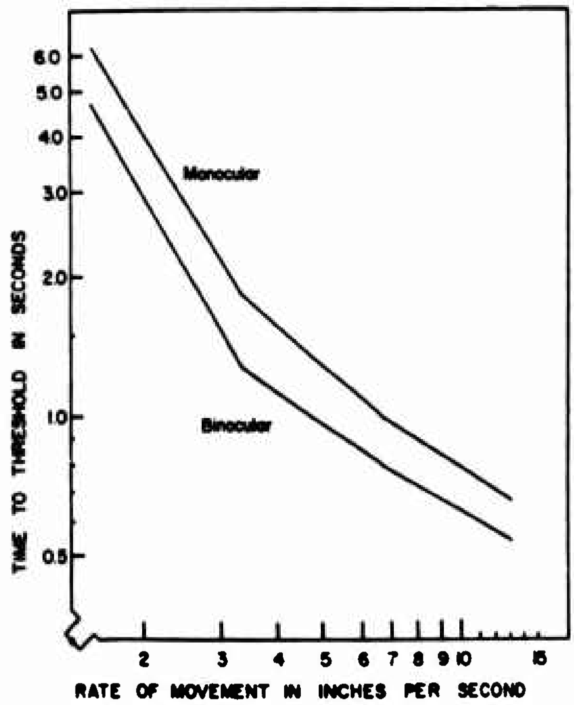

Figure 20. Observation Time Required to Achieve 75 Percent Correct Response as a Function of Target Speed on Movement in Depth

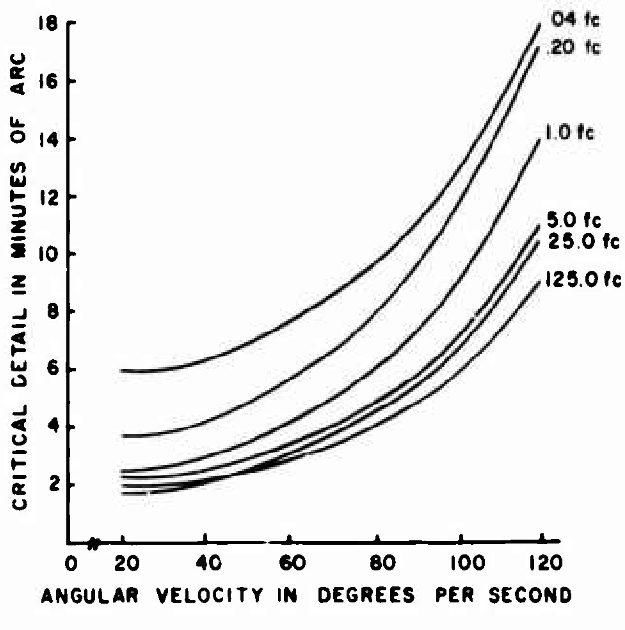

Figure 21. The Mean Dynamic Threshold Visual Acuity for Six Subjects Obtained During Rotation in the Horizontal (after Miller, 1958)

the relationship between DVA and speed is more linear and a decrement in performance starts at 75 deg per sec. (39)

DVA shows a more gradual increase with illumination than SVA. However, an illumination increase which does not improve SVA any more is still beneficial for DVA (Ludvigh and Miller). DVA is highest in the fovea and less in peripheral vision.

The reports cited up to now concern motion in a frontoparallel plane. A few experiments about DVA on motion in depth have been carried out by the Department of Engineering at UCLA.

One cannot adequately predict DVA from SVA probably, because with the former an additional ocular mechanism is involved, namely the function of the extrinsic eye muscles. (40)

In conclusion, conditions favorable for DVA are a slow apparent or actual movement, a long tracking time which creates the opportunity for long tracking distance, and good illumination."

i. Location of Objects

"The position of an object in space in relation to the observer is specified by its direction and its distance. For understanding of the perception of direction, an understanding of the concept of the "local sign" is necessary. When a retinal area is stimulated by an object in the visual field, one has the impression that the object is located in a definite direction. This is the local sign of the retinal area. The local sign of the fovea shows that the fixated object is in the direction of the primary line of sight. All retinal elements on the nasal side have local signs for the temporal visual field, and all retinal elements on the temporal side have local signs for the nasal visual field.

The direction of a point in space which is not fixated can be specified by its angle θ of excentricity from the primary line of sight of one eye (or at great distances from a joint primary line of sight) and the meridian angle ϕ, produced by the plane of regard (which contains the two primary lines of sight) and the plane containing the lines of sight to the fixation point and to the object point (See the specification of the glare source in space, Figure 16.).

The recognition of depth or distances occurs by virtue of distance factors or cues provided by the objects and their arrangement in space. One can distinguish two main groups of factors: those which provide distance perception only in binocular vision, with stereopsis as "the primary factor," and those which function also in monocular vision. The latter are also known as secondary or empirical cues because they may depend, at least in part, on empirical associations between distances of known objects and their retinal images. The recognition of the tridimensionality of a form is also a function of distance recognition, since we perceive parts of the form as being differently located in depth.

Stereopsis is produced by a difference of the images in the two eyes (horizontal disparity). It permits recognition of "relative distances," namely, that one object is nearer than the other, but not its absolute distance from the observer. Stereopsis is very effective in near vision, but it contributes very little beyond 200 m. It is entirely ineffective beyond about 1000 m.

Similar to other visual functions, stereopsis is impaired by dim illumination and also by short exposure. Influences that offset the pattern of horizontal disparities may produce apparent distortions in space, for instance, when the retinal illumination of one eye is dimmer than that of the other eye. In this case, there will be a difference in perceptual latency time, and the messages arriving synchronously at the visual center from the two eyes stem from different time periods of stimulation. When observing a moving object, this may lead to a depth distortion known as the Pulfrich stereophenomenon.

The importance of illumination perspective for depth perception can be appreciated when driving in a dense sunlit fog, where diffuse light illuminates the objects from all sides evenly. Aerial perspective results from the fact that contours, texture, contrasts, and color of distance objects are less clearly defined than those nearby (primarily due to atmospheric haze). A gradient of haziness is an indicator of changing distance, but it is not as compelling as other distance cues. It is variable with the condition of illumination and the weather.

Motion parallax (motion perspective) as a distance cue has been mentioned already in the section on motion. One can produce motion parallax, which is actually a change in overlay of objects, by moving the head from side to side. When fixating some intermediate point, objects nearer than the fixation point appear to move in the opposite

direction, while objects in the plane of the fixation point do not show a shift, and the objects farther than the fixation point appear to move in the same direction as the head. The farther the object of attention is from the fixation point, the greater the apparent speed and displacement. Thus, a gradient of motion parallax serves as a cue for judgment of distances.

When an object is perceived nearer than its true distance, for some reason, it appears smaller because the retinal image does not change accordingly. If the perceptual distance is larger than the actual distance, the object will appear larger because the retinal image did not diminish accordingly. This "lawful" illusion explains to a great extent why the moon appears larger at the horizon than at the zenith.

Distance perception becomes very difficult in an empty field, that is, in a "structureless" field. It is known that distances are usually overestimated when flying over snow fields. A stationary light in a dark surrounding is usually underestimated in its distance. As long as a light or object has a perceivable dimension, its change in size makes it possible to recognize that it recedes or approaches. Its brightness would not change, unless it perceptually becomes a dimensionless point. In total darkness this occurs at an angular subtense of 8 min and less. For instance, a light of 6 in. in diameter would appear as a point from a distance of 214 ft or greater. When a perceptual point recedes, its brightness diminishes, but this is slower than the diminishing illumination at the eye (which follows the inverse squares law).

In a structureless field a stationary light, when constantly fixed for several minutes, may start to move. This illusion of motion is known as autokinetic movement.

Psychological factors, for instance, the phenomenon of size constancy also play a significant role in distance seeing."

j. Color

"Brightness differences are primarily responsible for the detection of targets, but color adds an "attention getting" quality.

When one determines the minimal radiant energy that is necessary to perceive the different wavelengths of the visible spectrum and

plots this energy against wavelength, curves such as those in Figure 22 result. The lower curve is obtained by using the dark adapted eye at a peripheral retinal region in pure rod vision. The upper curve is that of pure cone vision, obtained in the fovea. When comparing red (the whole wavelength range above about 620 m μ looks red) and green (approximately 510-550 m μ), the striking difference is that red requires more energy than green in order to be seen. The difference is by far more obvious in scotopic than inphotopic vision. In the language of the illuminating engineers, this means that red affords less lumens per watt than green and that its luminous efficiency is lower at all stages of vision.

The luminous intensity producing attribute of radiant flux, usually expressed quantitatively in terms of its luminosity factors for each wavelength, is termed luminosity. Luminosity parallels luminance, whereas brightness parallels the logarithm of the luminance. In an equal energy spectrum, the luminosity maximum is at 510 m μ in scotopic vision and at 555 m μ in photopic vision, as can also be seen from the reciprocal of the energy amounts in Figure 22. In mesopic vision, with decreasing illumination, there is a gradual change from photopic to scotopic luminosity in retinal areas containing rods and cones. The foveal luminosity remains the same in photopic and in mesopic vision (except for some insignificant deviations). When a red and a green area each subtending, at the eye, an angle of over 2 deg (larger than foveal extent), both have a luminance of 20 mL, for example, then they appear equal in brightness. When both are darkened by the same filter down to a low mesopic level, the green appears brighter (Purkinje phenomenon).

Color perception is mediated by the cones.

Rods only mediate perception of brightness differences. A dim spectrum appears achromatic and colorless. The difference (in luminance or other units) between the achromatic and chromatic threshold of a wavelength is known as the photochromatic interval. It follows from Figure 22 that red has a very small photochromatic interval and some reds have none at all. Thus, red practically remains red down to the point where it entirely disappears whether perceived foveally or peripherally. When decreasing the luminance of a green light, it disappears in strictly foveal vision practically without a photochromatic interval, but when perceived with a retinal area containing rods and cones, it gradually loses its color and becomes whitish until it finally

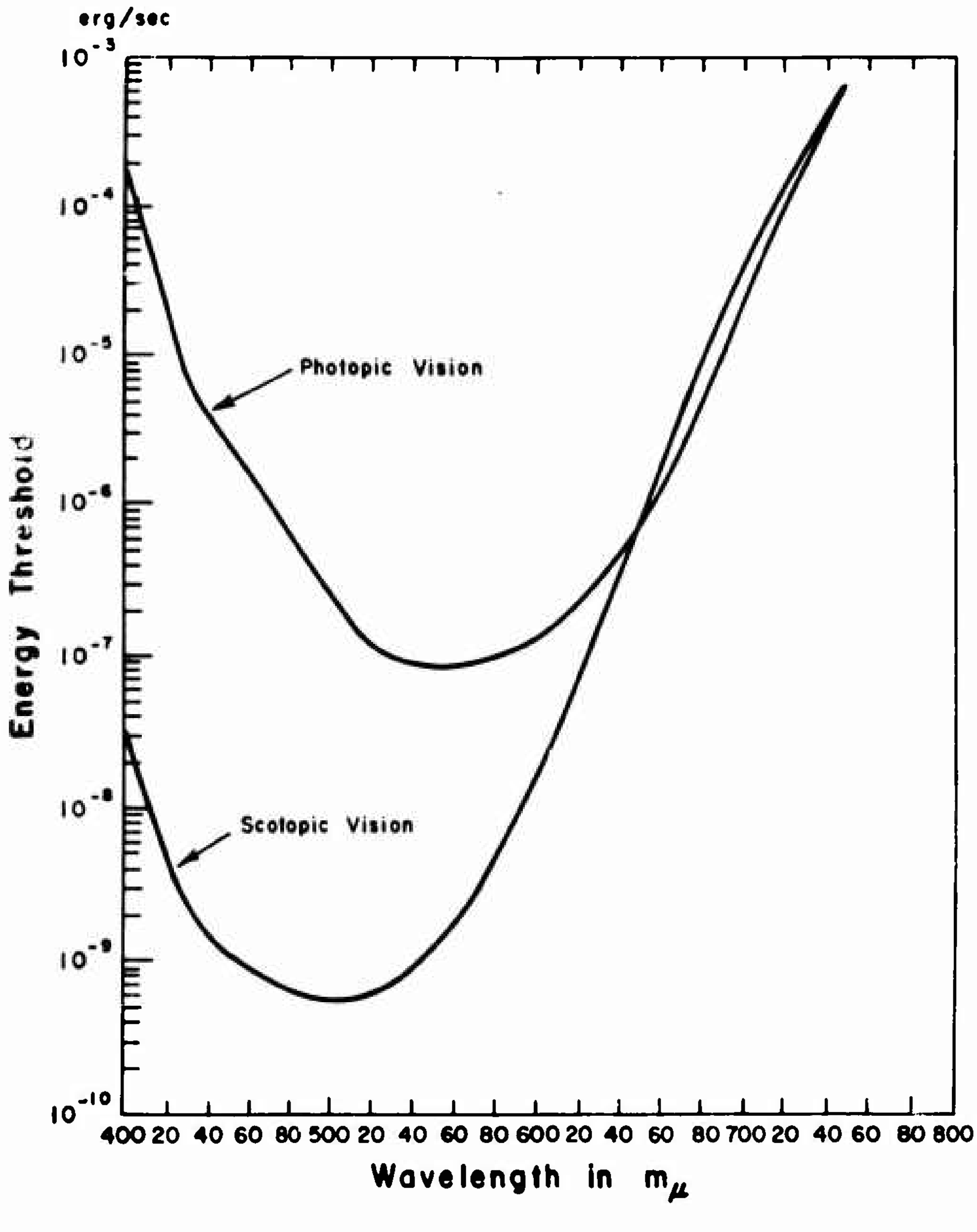

Figure 22. Thresholds of Spectral Energy in Scotopic (Rod) Vision and in Photopic (Cone) Vision

disappears. Green remains visible at lower luminances than red, but it does not keep its hue.

When measuring the visual fields, in photopic vision, with red and green targets of equal and constant saturation and luminance the limits of correct identification of the color (chromatic limits) are the same. Using red and green targets of equal low luminance on a dark background the chromatic limit would be larger for red than for green, but green could be perceived farther peripherally than red, since its achromatic limits are much wider.

The perceptual latency time is slightly shorter for red than for green and blue in photopic vision. In scotopic vision, the reverse seems to be true.

When focusing at distance, the eyes of hyperopes seem to be more adjusted to short wavelengths, and myopic eyes are adjusted to long wavelengths. Hyperopic eyes focus parallel rays of light, with accommodation relaxed, behind the retina .. myopic eyes focus in front of the retina. A population study shows that the mean refractive error is slightly shifted toward hyperopia. Thus, more persons should see green more clearly than red when looking at distance.

As already explained, red lights may be judged farther than green lights (in binocular vision and especially at short distances), by about two-thirds of the population, due to chromostereopsis. (41)

Color perception is not very reliable at threshold intensities or at small subtenses. Under these conditions, normal color vision approaches that of a blue-yellow blind or tritanope, hence this phenomenon is known as foveal tritanopia. Only yellow-orange and blue-green retain their hue and thus are especially well adapted for use as signal colors.

In true aqueous fog, all colors are scattered about equally. In the haze of smoke or dust, short wavelengths are scattered more than long wavelengths. This reduces the intensity of blue and green signals more than that of reds.

Congential red-green deficiency is found in about 8 percent of the male population and 0.4 percent of the female population. The color deficient have difficulty discriminating red, green, and yellow, whereas

yellow and blue appear to them qualitatively very different. The distinction of red from green is greatly improved when using orange-red and bluish-green. There are two main groups of red-green deficient. The protans, comprising the milder type of protanomals and the stronger type of protanopes, and the deutans, comprising the milder type of deuteranomals and the stronger type of the deuteranopes. About 2 percent of the male population are protans and 6 percent are deutans (females 20 times less of each). An important difference of the two groups is their perception of the long wavelengths, and in general in their spectral luminosity functions. The protans perceive the spectrum shortened at the red end and their photopic luminosity curve is shifted toward green. The photopic luminosity curves of protanopes and deuteranopes have been compared to those of the normal trichromat. (42) The weaker forms have similar deviations in their luminosities. In the short wavelength range, the three forms show no appreciable difference, but in the longer wavelengths range the protans have a very obvious loss in luminosity and the deutans show a gain. It is understandable from the luminosity curves that the deutans see at least the signal lights, although they do not always identify the colors correctly, whereas the protans sometimes do not see red lights at all or they see them too late."

3. DISCUSSION

a. General

The preceding discussion of the anatomy and function of the eye could be elaborated to almost any degree desired. However, it does not seem pertinent to the purposes of this investigation to elaborate at length and in great detail the various sections of the foregoing presentation. Although many subtle and interesting effects have been observed in the past century and a half of research into vision, these generally have no place in a study which aims to mark out the important factors in night reconnaissance. Only those factors which can make a significant improvement in the observer's chance of seeing a target are important here. When this study began, the possibility of applying some obscure effect to that end was believed to be a significant possibility. Although some such effect may exist, it has not been discovered. Consequently, it is believed to be most useful to bring together here the limits established for seeing, in terms of color, brightness levels, contrast, etc., and to show how these can be employed in the selection of an illuminant.

b. Chromaticity

For the purpose of describing in a quantitative manner the colors produced by flares, the chromaticity diagram of the C. I. E., which is widely used, is very convenient. A typical diagram is shown in Figure 23. The line y = 0 is known as the alychne, or lightless line. The short wave extreme of the spectrum locus comes close to it. This indicates that a response may be evoked in the standard observer by radiation in this region, but flux in the 0. 380 to 0. 440 range is only slightly luminous. It should be noted that only points lying inside the spectral color locus are physically realizable; that the point at x = 1/3, y = 1/3 is the white point of a source radiating equal energy at all wavelengths; that the curve labelled with temperatures represents the color produced by a full radiator. Judd's article in Steven's "Handbook of Experimental Psychology" gives a good, concise description of the various theories of color vision and the related defects of perception as well as the construction of the chromaticity diagram. (44) It will suffice to note here that a line drawn from the white point through the point representing a particular source will intersect the spectral locus at the dominant wavelength which is representative of that source. The excitation purity of the source is defined as the ratio of two lengths; the length from the white point to the source point is divided by the length to the spectral locus. Obviously, spectral colors will have an excitation purity of 1. 00.

The use of the chromaticity diagram may be seen from the following example, using the lines labelled A and B on Figure 23. A sodium nitrate - magnesium flare was burned and colorimeter data from it gave a dominant wavelength of 0. 582 microns, excitation purity of about 80 percent. This data plots of Figure 23 as line B. The dominant radiation from sodium occurs at 0. 5890 and 0. 5896 microns. The major visible atomic line radiation from magnesium is found from 0. 5167-0. 5184 microns. Radiation of these wavelengths and of spectral purity is located on the U-shaped curve. A line, A, connects these two points and passes through all the points that can be obtained by admixtures of these two radiations. The point at which A crosses B indicates that a color purity of about 95 percent would be produced if only these radiations were produced by the flare. It is apparent that radiation of other wavelengths must be present, as it is in fact.

A term used widely in the pyrotechnics industry and not employed elsewhere is "color value." This is defined as the ratio of

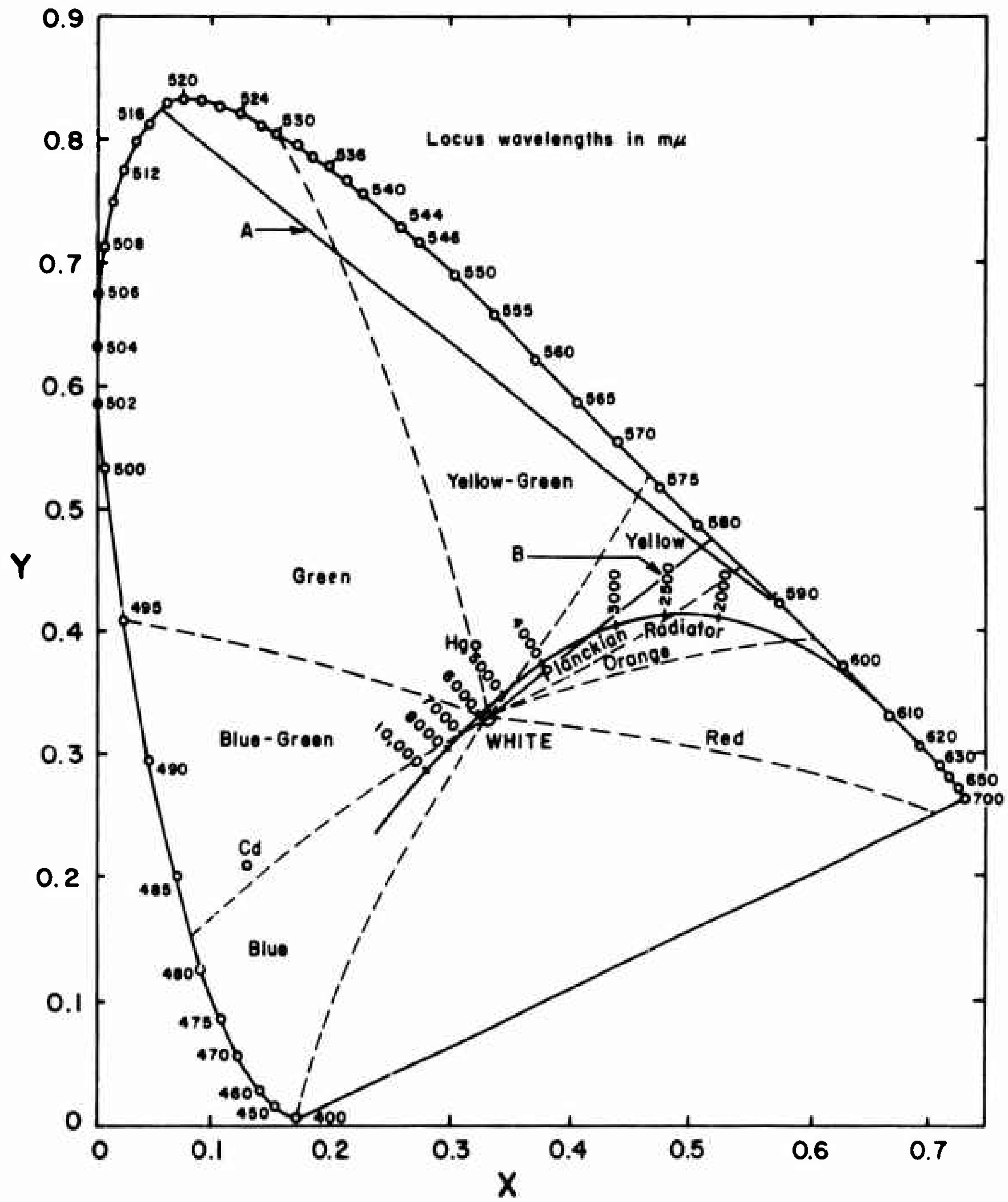

Figure 23. Chromaticity Diagram

the readings obtained from two photocells, one filtered and one unfiltered. The color value is the number obtained by dividing the filtered reading by the unfiltered reading. This ratio is accepted as a measure of the visual depth of the flame color. It is not as useful a quantitative method for comparing results between laboratories as the dominant wavelength and purity specifications, which are to be preferred.

c. Training

The process of conversion of the light stimulus into an appropriate visual sensation is influenced by many variables; the changing sensitivity of each part of the mechanism, the state of health of the observer, the state of activity of the other sense organs, and many others. As any magician can demonstrate in a short time, visual sensations are often poor guides to the nature of objects. Because of this uncertainty, information about the physical world obtained from the quality and magnitude of visual stimuli must be regarded with a certain skepticism. Nonetheless, constant training results in the acquisition of extremely acute senses. The trained hunter will see a deer standing in the forest edge at dusk, which the city dweller would never notice.

The first conclusion reached in this study, then, is that thorough training of aerial observers is essential to success in target detection.

d. Discrimination

Granted that the observer is properly trained, the ability to detect a target depends upon processes that may be lumped under the term "discrimination." While the word has unpleasant connotations in the current social environment, in the present usage it means "to distinguish by exposing or discerning differences." It is therefore pertinent to examine the factors on which these differences are based. Static targets will be examined, first, then moving targets.

At luminance levels which exceed 0.1 candle/ft^2, the standard photopic observer's spectral response exists; at levels below 0.0001 candle/ft^2 the scotopic response is produced. At levels of luminance between 0.1 and 0.0001 candle/ft^2 the response is a mixture of these two types. Remember that luminance is the product of the luminous reflectance of the object, the illumination and a cosine factor. The measured values of the luminous reflectance of natural objects range from 0.05 to 0.90, with median values around 0.25. (45) The dominant wavelength for commonly encountered natural objects ranges from

0.575 micron to 0.585 micron at a purity of about 0.30. The reflectance of untanned Caucasian skin varies from 0.30 to 0.50 in the visually useful range of the spectrum. (46) That of dark-skinned races would of course be less.

From the preceding comments it is evident that the objects the military observer is to detect and recognize do not usually differ greatly in their ability to reflect light to the eye from whatever source is present. That is, the foliage, ground, clothing, equipment and human skin present in a target area will all reflect similar amounts of light to the observer. Brightness contrast is generally poor under these conditions. Further, the reflected light must be at a level greater than 0.1 candle/ft^2 if color vision is to be fully effective as a means of discrimination. In view of the relatively low visual reflectance of most materials, a further increase in source intensity beyond that required for a specified illumination because of range is imposed.

As an aid to acquiring some feel for the relation between one's experience, and the numbers that are used in quantitative work, consider the illumination produced by full sunlight and by a full moon for reference purposes. These levels are, respectively, 10,000 ft-candles and 0.01 ft-candles. At the latter level, color contrast as a means of discrimination is becoming useless. At twilight, a level of around 0.3 foot-candles is found. Finally, recall that acceptable lighting practice calls for a level of 10 ft-candles to 40 ft-candles in the office and home. See also Figure 24.

The preceding discussion has taken no account of the motion or lack of it at the target. It is a fact commonly known that moving objects are far more readily detected. Equally apparent is the tendency of a sentient military target to remain motionless when the presence of an observer is likely. From a military standpoint the presence of a moving target must be considered somewhat fortuitous. Examination of the data that have been published on detection and discrimination of moving targets (as well as static targets) reveals a serious lack. Understandably, the data on such a complex phenomenon have been taken under laboratory conditions. In these studies, all reasonable efforts have been made to eliminate complicating factors and arrive at quantitative results. Unfortunately, this has also eliminated most of the resemblance to actual field conditions. An absolute threshold for the detection of movement under laboratory conditions is found to be from about 1 to 10 minutes of arc per second which varies with the illumination on the target, its location in the field of view and the duration of the observation. (43)

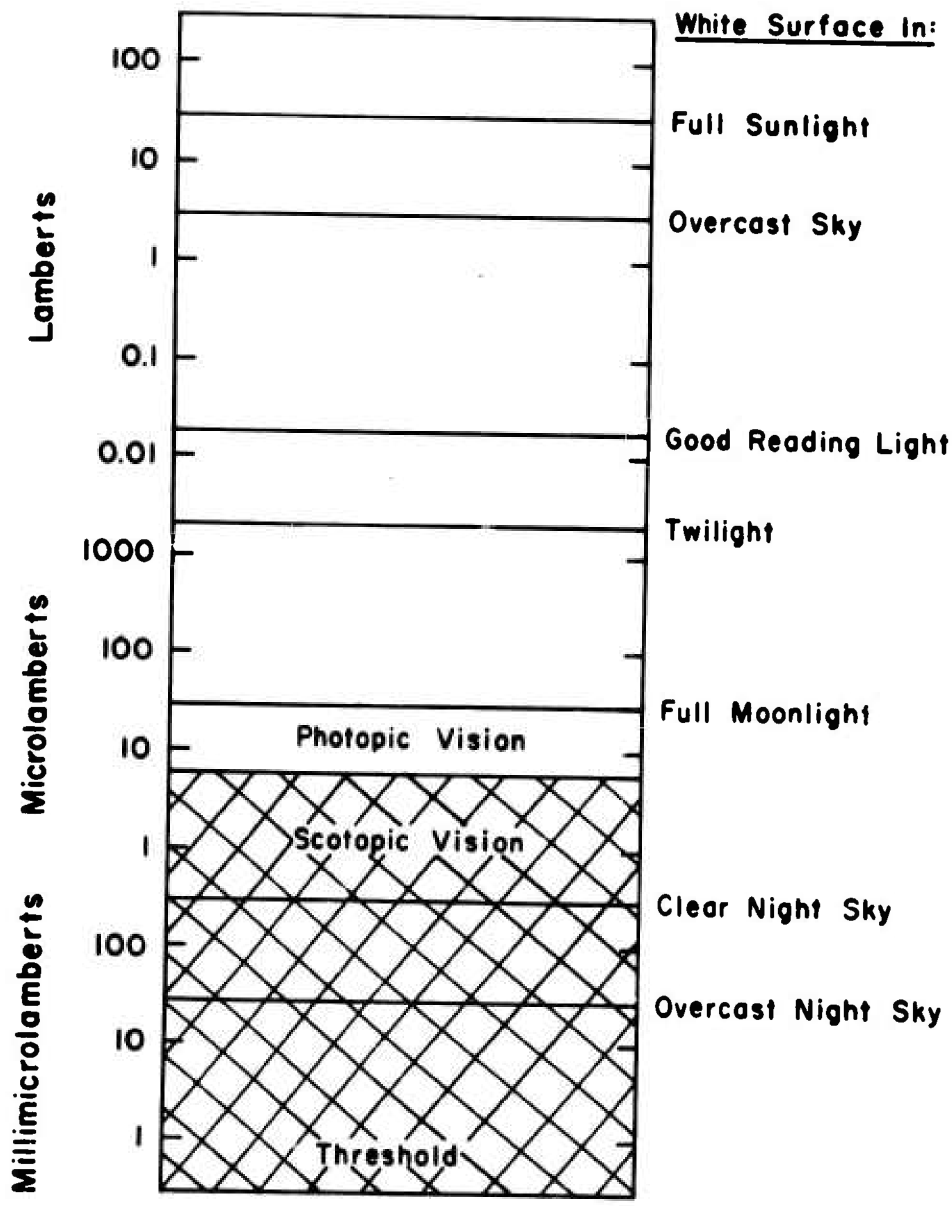

Figure 24. Range of Light Intensity Response of the Eye

To relate common experience to these numbers, it is easy to compute that a man running across the line of sight at a range of 1000 yards will be traveling at 10 ft/sec., or about one-third the speed of a champion sprinter, to cover 10 arc-minutes per second.

However, these lower limits of detectable motion were obtained under relatively ideal conditions. The study of the detection limit for motion should be extended, to obtain data which represents real observations, but the analysis problem appears to be too difficult. Quantization of the conditions which exist when a camouflaged object moves in front of the complex back-drop of jungle foliage appears to be beyond our current abilities. With these limitations of theory in mind, it may be noted that a target luminance of about 0.2 candle/ft^2 is required to discern motion at a rate of 4 arc-minutes per second in 1/4 second of observation. If observation time is reduced to 1/8 second, the rate increases to about 10 arc-minutes per second.

The conclusion reached is that, in the absense of data from more realistic experimentation it is only possible to rely on experience in the field as a final criterion. A minimum level of illumination for the detection of motion may be somewhat less than for the discrimination of a static target. It should be at least a high enough level to result in a target luminance of the order of 0.2 candles/ft^2. This implies an illumination level on the order of one foot-candle. In some circumstances levels as low as 0.1 foot-candle have been found acceptable.

e. Brightness Contrast

This term refers to an achromatic difference in luminance of two relatively adjacent areas in the visual field. By means of brightness contrast, one distinguishes such objects as the black type printed on a white paper. It is another complex process that has been studied by many investigators. Brightness discrimination is a closely related phenomenon. No quantitative law has been deduced by which one may calculate in advance the probability of distinguishing an object by its brightness contrast alone. Both Graham and Bartley, in discussing this subject point out the interrelationship between the size of the test object, the level of luminance of the surrounding area and the difference in level between the object and its surroundings. (43, 44) Because of these several factors, it is difficult to apply the concept to the detection of military targets in a quantitative manner. If it is assumed that the background luminance is of the order of 0.1 candle/ft^2 - as it may be

in a night reconnaissance situation - the just noticeable brightness contrast is of the order of one percent for a target subtending seven minutes of arc (i. e., about six feet at 1000 yards). This, however, is a result obtained in the quiet surroundings of a laboratory and almost certainly does not apply when the observer is subject to stress. When stress is influencing the observers performance, a contrast value ten times higher might be assumed to be required.

The conclusion reached here is simply that our knowledge is in an unsatisfactory state. One can only conclude that it is advisable to maximize the effect of the contrasts that exist as defined by luminance differences by supplying as much light on the target area as possible.

f. Color Discrimination

The importance of color differences and brightness differences in detecting targets are roughly equal, although brightness differences still exist at levels of illumination too low to evoke a color sensation. The ability of the eye to discriminate colors depends, again, upon the level of illumination but in addition upon the spectral distribution of the light source. Under a "white" source of light, and laboratory conditions free from stress, the number of spectrally pure colors that can be identified is of the order of 150. (47) This is deduced from the plot in Figure 25 of hue discrimination as a function of wavelength. The minimal difference occurs at 0.480 micron and 0.600 micron and is about 0.0005 micron. At the wavelength to which the photopic eye is most sensitive, 0.535 micron, sensitivity to differences is much lower - about 0.002 micron. Separate color names cannot be assigned on the basis of these differences, but they are nonetheless real. Again, under conditions of stress the ability to discriminate small changes degrades. In addition, if the spectral distribution of the source is not essentially white but such as to produce a colored light, the number of colors that can be identified will be greatly reduced. This effect might be useful under some conditions. If a target is illuminated with light of its own color and the background is of a different color, the brightness contrast between target and background can be enhance. The effect increases as the difference in colors becomes greater. The result is useful even when the saturation or purity of the colors is low. Reliance on color discrimination alone in steady white light when this latter condition exists might not result in detection, whereas the use of colored light as the illuminant can increase the contrast to a detectable level.

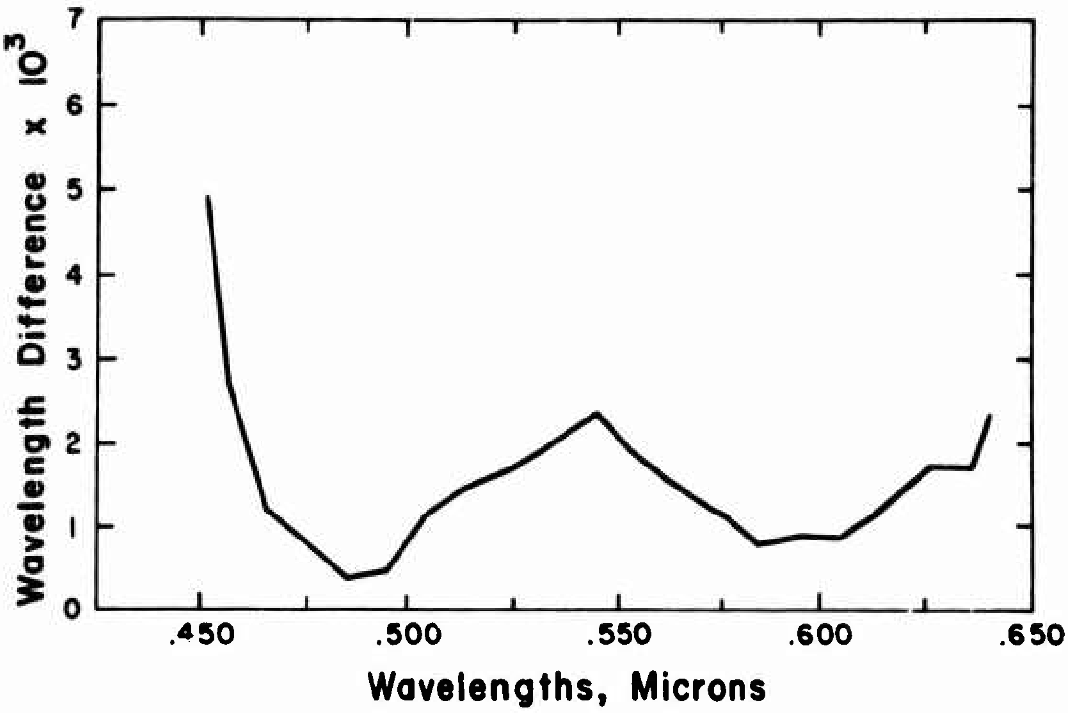

Figure 25. Threshold for Hue Discrimination

g. Flicker Effects

Flicker effects are produced by intermittent stimuli arising from periodic variations in the brightness of some object in the visual field. It is noted experimentally that the alternations of the stimulus are no longer perceived after the frequency exceeds some value known as the "critical flicker frequency" or CCF. The extreme complexity of visual phenomena is again evident in studies of flicker. For example, the CCF was found to vary from 12 per second to 55 per second as the illumination ratio of the surround to the test area varied from 0 to 5 and the diameter of the test area - the area which flickered - varied from 1.5 to 400 minutes of angle. As the surround grew brighter and the test area larger, the CCF increased. (43) There is also evidence that a variation of CCF exists for different modulating wave shapes and for different retinal illuminances. (43) Most of the studies of flicker phenomena - and Graham references over 350 - indicate that a maximum effect exists in the frequency range corresponding to the alpha rhythm of the brain. This rhythm varies with the individual and his physical state, but is of the order of 8-13 cycles/second.

Experimentation was carried out during the current study to explore the possibility of using alternated flickering light sources of different wavelengths in order to enhance visual differentiation between target and background. The idea behind this scheme was to select a pair of light sources of different colors which would emphasize any reflectance contrast of the target while very little reflectance contrast would be apparent on the background. In this manner, the target could be made to flicker due to the low and high reflectances for the alternating colored lights whereas an apparent fusion would occur on the background. This increased contrast between target and background was expected to improve target perception, especially on moving targets where a strobed effect would occur, and enhance recognition. A similar system has been previously used to distinguish poor imitation green from real green foliage wherein a great many artificial greens had a very low reflectance at 700 millimicrons compared to natural green foliage. (50) In this earlier work, two band-pass filters were prepared which had different transmission characteristics in the red region of the spectrum. The filters were designed so that in viewing natural green foliage illuminated by sun and sky light, the natural foliage appeared equally bright, as well as roughly the same hue, using either filter. However, poor imitation green appeared very much darker using one filter than the other. Alternate use of the two filters at about 1/2 second intervals produced no change when viewing the foliage but caused the poor imitation green to flicker violently.

The present experiments were performed in a light-tight laboratory using an appropriate set of light projectors located 17 1/2 feet from the target. Visual observations were also made from this distance. Two studies were carried out; one, considerably idealized but capable of some quantification, used various commercial art papers while the other used a common house plant and an army fatigue jacket.

Experiment I: Effect of Flickering Light Sources on Commercial Art Papers

The initial study using commercial art papers was primarily carried out to develop the method and select the most effective filter combinations and chopping rates. Visual observations of the reflectance produced on a number of art papers using various Wratten filters were made. Five colored art papers were selected for study which contained either red or green. The choice of color was based on the prevalence of green, blue and brown objects in natural scenes. The pairs of art paper samples used are described in Table I.

The same pair of filters was used over the light sources in all tests, namely Wratten No. 26 (red) and Wratten No. 64 (green). The art paper samples, which measured 6 3/4 inches wide by 12 inches long, were mounted side by side on a low-reflectance black cloth background, 17 1/2 feet from the projectors. Two 50-watt projectors were utilized with a masked output beam which illuminated only the art papers. The two light sources were alternately chopped at frequencies varying from 6 cps to 18 cps or higher, if desired. The data from this experiment are presented in Tables II through VI. The light source intensities were measured with a General Electric foot candle meter located one foot from the source; from these readings, the target illumination values were calculated. Chopping frequencies were varied from 6 to 20 cycles per second and the two light sources adjusted to produce a minimum amount of flicker in the green art paper and a maximum in the red as determined by visual observation. At this point, reflectance measurements were taken with the E. G. &G. Radiometer (without chopping) to determine the relative amounts of light reflected from the two art papers. In adjusting the two light sources for maximum contrast at the various chopping rates, it was found, generally, that the red-to-green light intensity ratio had to be increased with increasing chopping rate in order to achieve best contrast as observed by the eye. However, in the range between 12 and 14 cycles per second, best results were obtained for fairly high values of both light sources. In order to depict this observation graphically, one need only obtain the products of the reflected light values, thereby obtaining a maximum in the most effective range. These results are plotted in Figure 26. The absolute light intensity values found to be most desirable at the distance used, i. e. , 17. 5 feet, would necessarily have to be increased at greater distances in order to maintain the target illumination level. Correspondingly, apparent fusion at this distance would not occur at distances closer to the target. In other words, the target illumination level appears to be a sensitive variable in producing the observed contrast flicker.

Experiment II: Effect of Flickering Light Sources on Green Plants and Fatigue Jacket

A more realistic study was undertaken using a live, broad-leaved plant (Draecaena Cragii) and an army fatigue jacket. Prior to the selection of the most suitable filter combinations, individual reflectance readings were obtained for both the plant and jacket using a variety of filters. From this data, select filter pairs were chosen to cause either the plant or the jacket to flicker while maintaining apparent

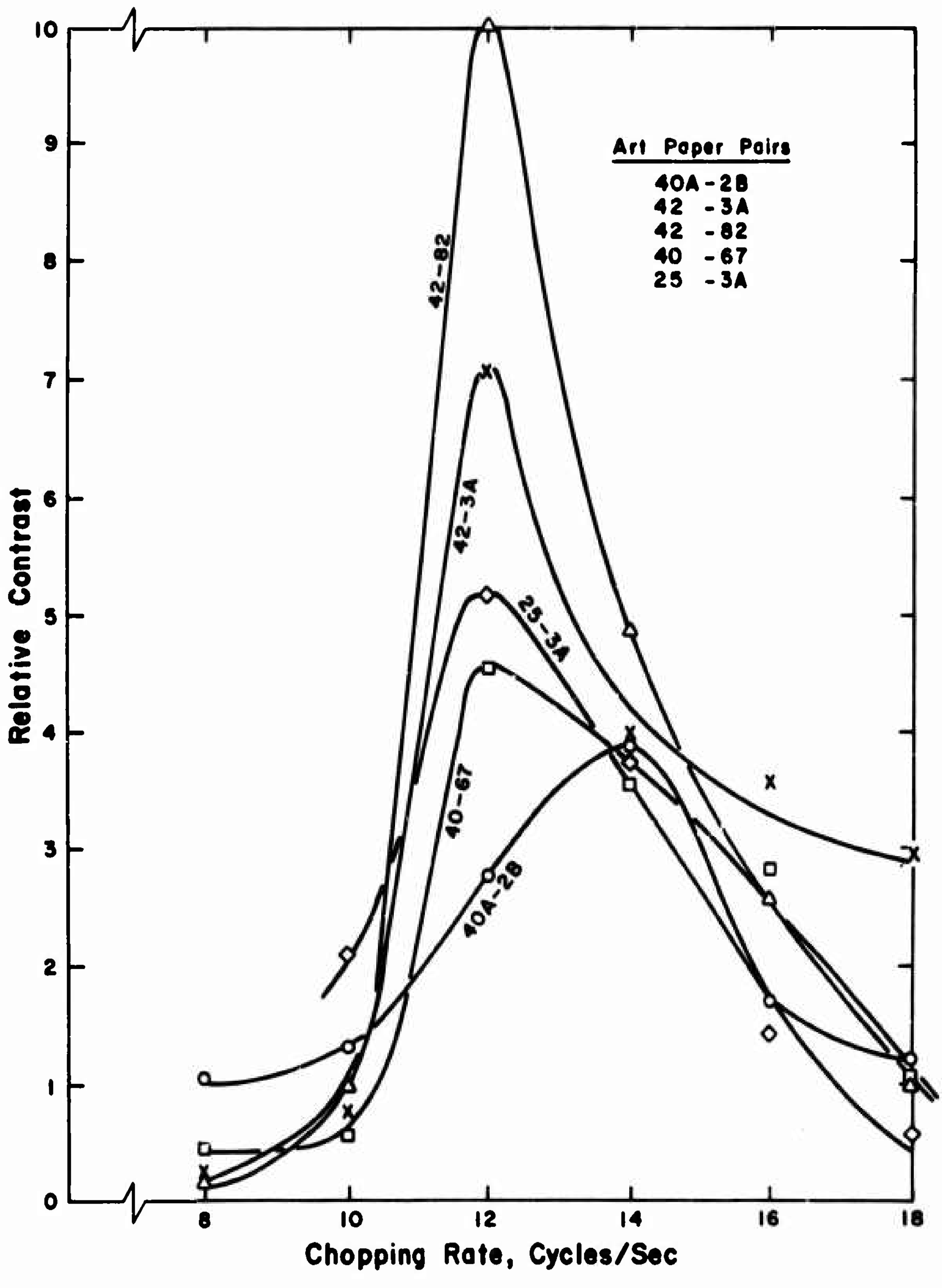

Figure 26. Effect of Chop Rate on Differential Flickering Using Red and Green Filters and Various Art Papers

fusion on the other. Illumination was accomplished with one 500-watt projector and one 200-watt projector located 17 1/2 feet from the target. As before, the two light sources were alternately chopped in the range between 12 cps and 25 cps. The results of this experiment are shown in Table VII. The best conditions for plant flickering were found to be at a chopping rate between 14 and 16 cps using Wratten filters #26 and #55 with a red-to-green light ratio of approximately 1.5. Best conditions to cause flickering of the fatigue jacket were obtained using Wratten filters #3 and #64 at chopping rates between 18 and 22 cps. With the particular plant and army jacket used, it was possible to obtain good differential flickering using only a red or red-orange filter. Due to the higher reflectance of the fatigue jacket, under an appropriate light level, the flicker on the plant would be unnoticed at the distance observed while the jacket would appear to flicker violently.

Flickering light sources appear to show some promise, at least as shown on a laboratory basis. However, where targets are just barely perceptible from the background, it remains to be seen as to whether this method would produce improvement of sufficient magnitude to warrant the additional handware development costs involved. Furthermore, colored light sources whether produced through special pyrotechnic mixes or by filtering of essentially white light are of lower intensity than white light sources. That is, they produce lower illumination levels from a source of constant size and weight at a fixed altitude. Consequently, very large sources may be required to utilize the contrast enhancement produced by a colored, flickering source.

SECTION III

THE SOURCE

1. GENERAL COMMENT

The nature of this study has placed the emphasis with regard to sources on those which are of a pyrotechnic nature. Other sources are employed in night reconnaissance on occasion and should not be overlooked in the broad view of the problem of battlefield illumination. Such sources as plasma arcs, xenon flash tubes, carbon arcs, tungsten filament lamps, etc., have been used for special situations. At present, the gap which has long separated electrical sources from chemical sources appears to be closing. The development of more efficient means to generate electrical power is primarily responsible for the renewed interest in electrical sources of illumination. At the time this is written, the situation is very much in a state of flux; a discussion of the relative merits of chemical and electrical sources may be found in the literature. (48)

2. SPECTRAL DISTRIBUTION

The spectral distribution of the source is important to visual observation from several standpoints. It must, of course, emit useful amounts of radiation in the visible region of the spectrum, but granted this requirement, others still remain. The source may emit useful amounts in the visible, but also emit much more in nonvisual regions of the electromagnetic spectrum. If it does, it is then very inefficient. The emission may occur at wavelengths to which the eye is responsive, but to a lesser degree than at its photopic maximum response near 0.550 microns. Again, a lessened efficiency is the consequence, but the effect may be useful in special cases. In general, the spectral distribution to which the eye responds best at photopic levels of illumination is one similar to sunlight. A similar distribution will also serve for scotopic vision, although the peak response is then near 0.510 micron. This may be approximated by the radiation emitted from a full radiator at a temperature of around 6000°K.

It is not feasible from a practical point of view to produce a pyrotechnic radiator which operates at this temperature. It would probably be undesirable to do so in any case because of the huge energy loss in nonvisually useful radiation. This radiator would emit a total of about 5 kw/cm^2; the radiation would be distributed with 60 percent in the

infrared, 20 percent in the ultraviolet and only 20 percent in the visible region. Of this 20 percent, about 5 percent occurs in the .525-.575 micron band of high visual efficiency.

Most pyrotechnic light sources can be represented by superimposing some selective emission on the radiation from full radiators operating at temperatures in the neighborhood of 2500-3000°K. The peak of the full radiator emission occurs at about 1.0 micron, with 95 percent of it being emitted at longer wavelengths than 0.7 micron. The visibly useful radiation amounts to no more than 4.5 percent, usually much less. Such a source would be even less useful than the one discussed earlier were it not for the presence of selective radiation. This radiation is emitted by atoms and molecules excited thermally and is superimposed on the radiation produced from the solids and liquids in the flame. The selective emission wavelengths are not functions of temperature so long as enough thermal energy is available for their emitting processes to function, although the emitted intensity is strongly temperature dependent.

An extremely hot source can affect the wavelengths radiated from atoms and molecules and hence the spectral distribution by creating ions and dissociating the molecules. Ordinarily, pyrotechnic temperatures are below the level at which this factor becomes significant for most species employed.

The presence of the selective radiation from these thermally excited atoms and molecules is what really accounts for the usefulness of pyrotechnics in the visible region. By selecting the materials used in compounding the pyrotechnic, considerable control can be exercised over the wavelength(s) at which the selective emission occurs. By this means, red, yellow, green and blue radiation can be produced. The species which exhibit maximum color purity are those which produce red or yellow light, green normally being badly contaminated with yellow and/or red, while blue is hard to produce in sufficient intensity to be useful. Blue is not used widely because the spectral purity of blue light is even more degraded by admixtures of red and because of its poor visibility, which is the result of absorption in the eye as well as scattering and absorption in the atmosphere.

Colored flares are used primarily for signalling, yellow and "white" flares for illumination. The most successful illuminant flares are based on a composition containing magnesium, sodium nitrate and

a binder. When compositions of this nature are burned at ambient pressures in excess fo 300 torr, an extremely bright flame of high luminous efficiency is produced.

The flame appears almost white, when the flare is of the usual size, and not yellow as might be expected. The reason for the high luminosity and essentially white color lies in the selective radiation from the sodium and in the broadening of this radiation into a continuum. The continuum extends from about 0.4 microns to 0.6 micron. Data reported by Douda show that 44 percent of the total radiation in the visible may be ascribed to this continuum. His work indicates that the production of light by one of the larger flares in use, the MK24, represents abou' 11 percent of the energy produced by the flare reaction. (49) When compared to the three percent efficiency with which visible power is emitted by a tungsten filament at the temperature reached in a 1000 watt lamp, this is remarkable. An electrical source of somewhat similar spectral distribution has become available recently, as the General Electric Co. "Lucalox" high pressure sodium vapor lamp. Development of electrical energy sources of low mass and high power output may permit this type of lamp to complete with pyrotechnics.

In conclusion, it is apparent that reconnaissance needs in general are best fulfilled by a source which has a spectral distribution similar to sunlight. This is best obtained, at present, from pyrotechnic compositions of magnesium and sodium nitrate. The electrical sources may displace pyrotechnics in the next few years, as they are improved in output as measured by kilowatts per pound. Colored light is generally much less desirable as an illuminant because it is extremely inefficient in terms of luminous effect per unit weight or volume of the source. (Cf. Appendix, Tables XIV - XVII).

Under some conditions, colored sources may be useful as a means of increasing the contrast between the target and the background. The gain is apparently so dependent on matching the illumination to the target as to make its application useful only in very special cases. The results of experimentation on this point are given in Section II - 3. - g. More efficient pyrotechnic illumination sources can apparently be obtained by increasing the ratio of selective emission in the visible to the total emission and studies to accomplish this should be actively supported.

3. SIZE, NUMBER AND LOCATION

a. General

The relation between the position of the target, observer and source can exert a great influence over the visibility of the target. Many investigations have been directed to obtain an optimum solution to this problem. (51, 52, 53) It is necessary to evaluate the relative merits of specular reflections from equipment, contrasty or diffuse illumination, silhouette or frontal lighting, the number of illuminants required to achieve a specified illuminance level, etc. In addition, the same complicating factors that have been noted earlier are still operative. That is, the lighting can be specified with some accuracy for targets observed under laboratory conditions but practical field targets are too complex for a quantitative analysis and prediction of the requirements. The results of field studies that have been examined for this task are somewhat discouraging but indicate that an empirical approach can produce results. (52, 54, 55) Such studies would be expensive to conduct to the required extent of detail and replication; however, even the partial results would be of direct applicability to military needs as they became available during the progress of the study.

b. Size

In this section, size is related to the flux emitted by a single source; i.e., its intensity, not the weight or volume of a specific flare. It is assumed that some level of illumination on the ground has been chosen, and that the area to be covered with at least that level of illumination is known. The information on which these decisions are based is determined by the tactical situation. It is also a function of many poorly defined physical and psychological parameters but see Section II for suggestions in this respect.

The relation between the size of the source and the level of the illumination produced at a given distance is usually based on the assumption that a point source is present. In fact, if the major dimension(s) of the radiating surface are less than one-twentieth of the distance separating the source and target, the point source assumption is quite valid. For most field applications, a ratio of one-tenth would be entirely acceptable; the error in calculating the level of illumination from this assumption would be less than one percent.

Furthermore, the assumption of a point source results in the acceptance of a circular iso-illumination contour on a surface normal to the radius vector from the source. It will be assumed that the ground or terrain to be illuminated in a practical situation is essentially such a plane surface. If the illumination on a major terrain feature whose surface is not horizontal is to be found, the slant range along the normal to that surface should be employed in place of the altitude of the source above ground.

Calculation of the ground illumination is based on the following equation:

$$E = \frac{I}{h^2} \cos^3 A \tag{5}$$

The symbols are defined as

E = illumination in foot candles

I = source candela

h = source height in feet

A = angle included between the vector from the source to the point and the surface normal at the point

The effect of the cosine factor can be estimated from the following typical values:

A	cos A	$\cos^3 A$
0	1.000	1.000
10	0.985	0.956
30	0.866	0.649
45	0.707	0.353
60	0.500	0.125
80	0.174	0.053

At angles greater than 60°, the illumination is less than 12 percent of that directly below the source. This would appear to be a practical cut-off value, beyond which no attempt should be made to use the source.

The results of a similar calculation are given in Figure 27 to provide a basis for quickly estimating the radius of the circle at which a given source intensity will produce an illumination of 0.1 foot-candle. The curves in Figure 28 permit an estimate of the area covered by a 200,000 candela source for several values of illuminance. The line A in Figure 27 (with a slope of 0.71) indicates that the optimum height for a source is 71 percent of the radius at which the desired illuminance occurs, to maximize the illuminated area.

In the practical case involving a parachute flare as the source, some rate of change of altitude must be considered because of the gradual descent of the flare. The rate will be approximately 8-10 feet/sec if the source is a parachute flare of the type that has been used. Burning times will vary with the particular flare used, between (currently) limits of approximately 60 seconds and 300 seconds. A typical case would be the production of 1,000,000 candela for 180 seconds. During this time, the source will change altitude by about 1500 feet. The source must start at an altitude which produces the desired light level at the selected radius. If this is, say, 0.25 foot candles at 300 yards, the maximum initial height would be 1650 feet. The flare would burn out 150 feet above ground zero, at which time the illuminance at the 300 yard point will be somewhat below the desired level. This can be derived from Figure 29 in which the radius at which the illumination is 0.25 foot candle is shown for flares ranging from one million to sixty-four million candlepower. This figure was included because the present trend is toward larger flares which produce up to 25,000,000 candlepower. Future developments may result in even higher intensities. Figures 27-29 may be adapted to other values by multiplying the given source candela by the ratio of the desired luminance to the given luminance.

It should be noted in Figure 28 that an altitude change from 325 feet to 950 feet, a factor of nearly 3, changes the level of illumination at a radius of 700 feet only 25 percent. A much larger change is found in going 600 feet to the ground, or from 1300 feet to 700 feet. Knowledge of this region of minimum change of illumination for considerable variation in source altitude can be useful in maximizing the time duration of a desired level of lighting.

c. Number

The use of multiple sources may be desirable as a means of reducing the high contrast between lighted and shadow areas which

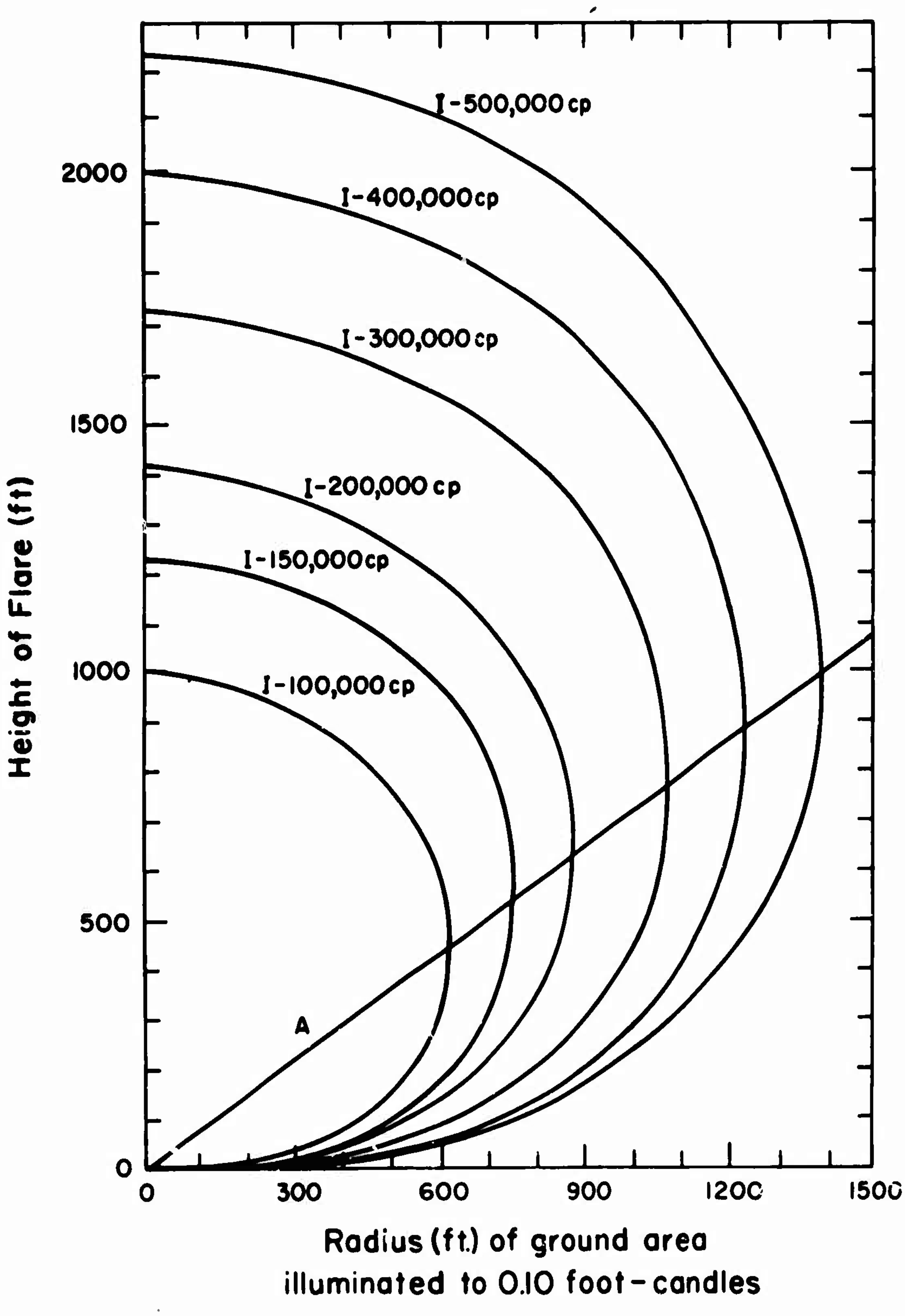

Figure 27. Illumination vs. Height of Flare, I = 100,000 cp to I = 500,000 cp

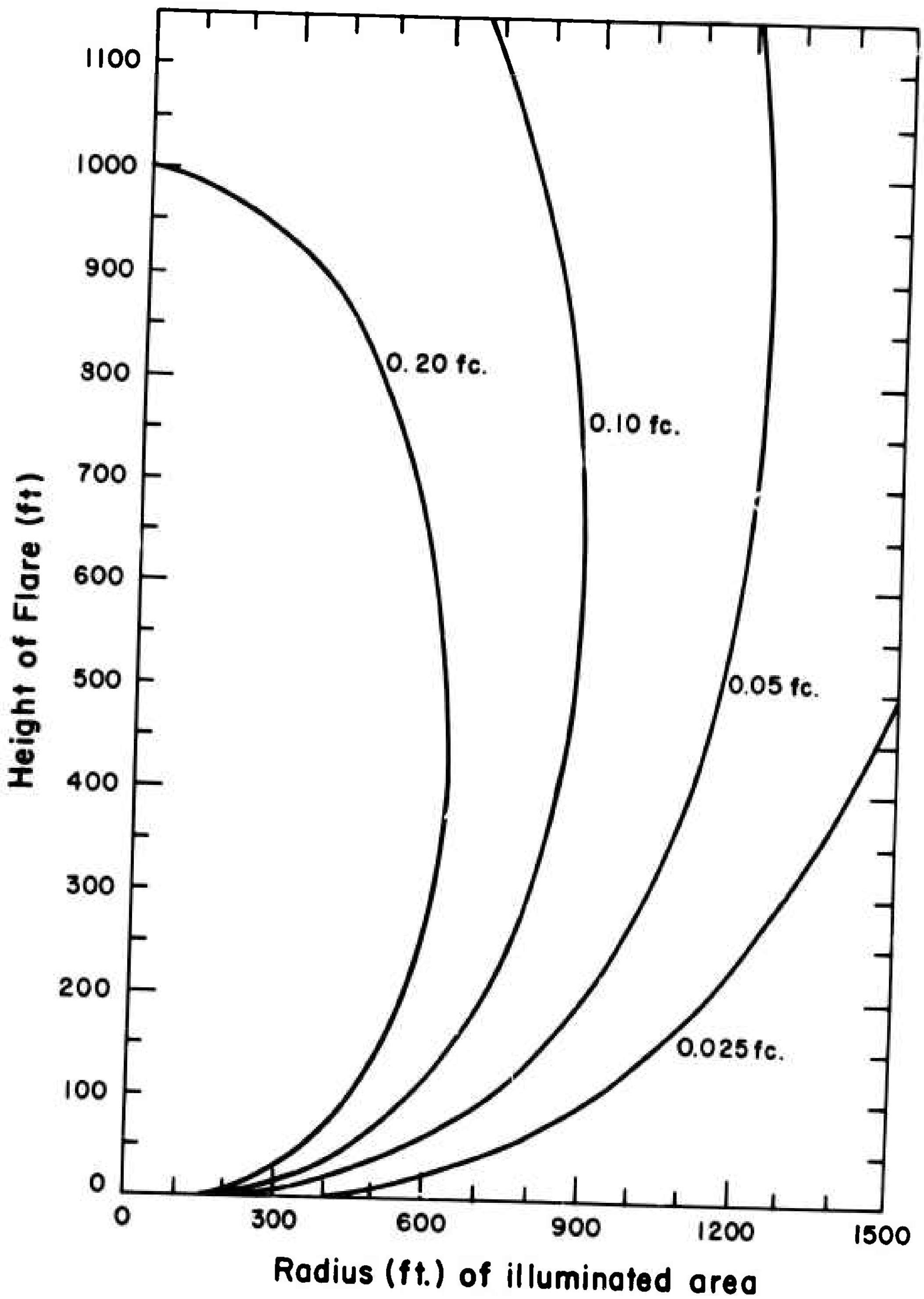

Figure 28. Flare Height vs. Illuminated Radius at Various Levels of Illuminance. Flare Intensity 200,000 cp

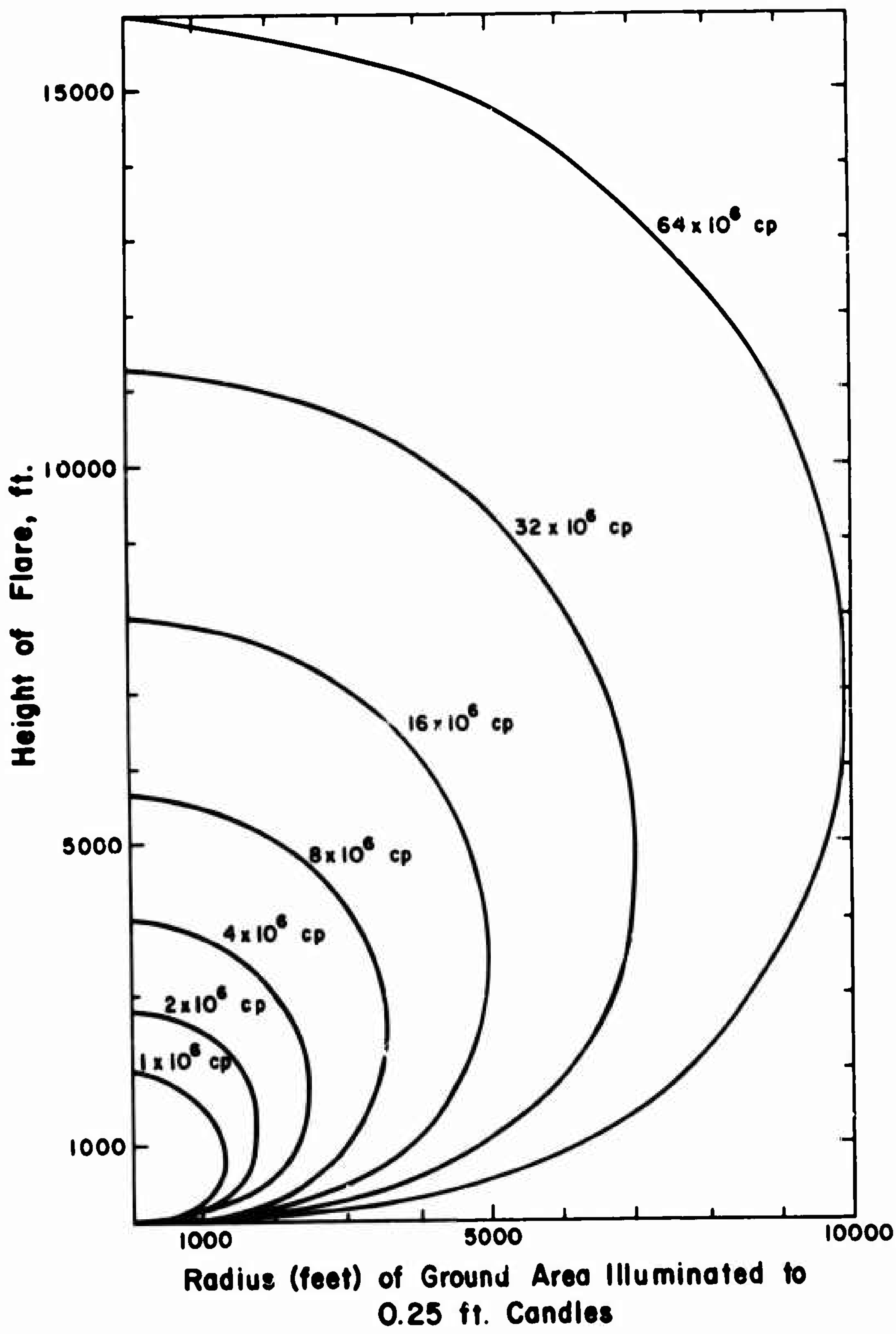

Figure 29. Illumination vs. Height of Flare $I = 1 \times 10^6$ cp to $I = 64 \times 10^6$ cp

characterizes a single source; as a method of increasing the illuminance when single sources of adequate intensity are unavailable; as a way to increase the duration of illumination. The last case can be considered as a special instance of the single source if the overlap in duration is not too great. The use of multiple sources to increase the illuminance requires as high a degree of simultaneity in functioning as possible. A multiple launch is to be preferred; sequential launching not only destroys the simultaneity of functioning but also distributes the units over an area. If the space separation is controlled by circling the launch vehicle, this may be minimized. The effect of space separation is not too severe if the distance between the units and the center of mass of the group does not exceed 10 percent of the source height. This separation may be difficult to achieve by sequential launch at relatively low altitudes if the aircraft ground speed is of the order of 500 knots. At 2000 feet altitude the desired 200 foot separation would necessitate launching every 0.25 second. This short interval is difficult to obtain with large flares which suggests that only simultaneous launch should be used, or a single larger flare, if point source illumination is essential. If it is not important to simulate a single source but it is required to increase the illuminance over an area, much larger distances between sources can be accepted.

Two situations are commonly encountered with respect to the pattern in which the sources are distributed. These two conditions will now be discussed in some detail.

If a long, narrow path is to be illuminated the number and spacing of the flares may be calculated from the following equation:

$$E_p = \frac{I}{h^2}\left(F_1\cos^3A_1 + F_2\cos^3A_2 + F_3\cos^3A_3 + \ldots F_n\cos^3A_n\right) \qquad (6)$$

The illuminance, E_p, will be in foot candles when I is in candela and h, the source height is in feet. The point, P_1, for which E_p is computed is directly below one of the sources. The value of F will be 0, 1 or 2 depending on the position of P with respect to the first and last source, S_n. See Figure 30.

When two sources, S_2 and S_4, are located symmetrically with respect to a source, S_3, above the point, P, the value of F_n is 2. If only one source exists, as S_1, the value of F_n is 1. When no source exists the value of F_n is zero. The value for E_p at P_1 is the maximum; a

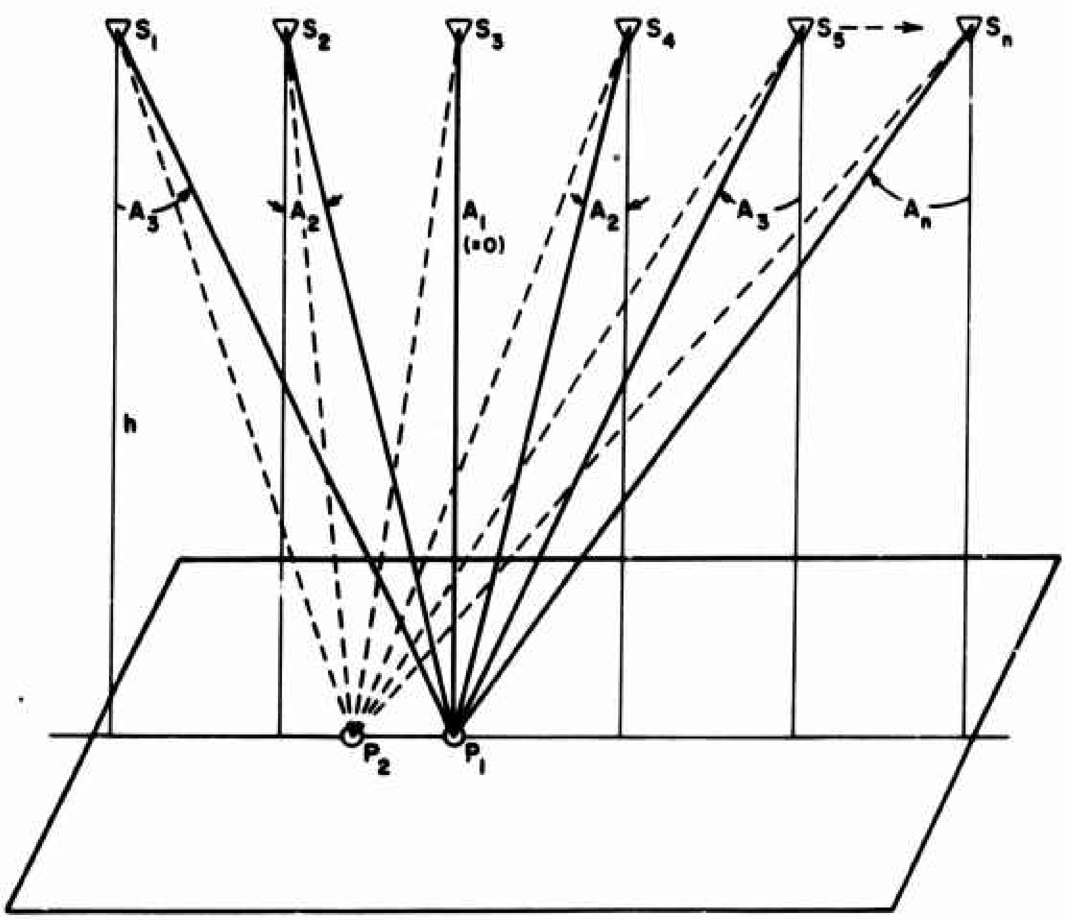

Figure 30. Linear, Symmetrically Distributed Source Geometry

minimum value can be computed which will correspond to P_2, midway between the sources. From a little consideration of the values taken by $\cos^3 A$, as A increases it is evident that four terms of the series are sufficient for many practical problems, and corresponds to selecting a point located midway of a seven-source string. The minimum value of E_P may be estimated as 80 percent of E_{P_1} for reasonable values of height and separation. While individual cases may arise in which a detailed calculation is required, in many cases a separation equal to 40 percent of the source altitude will be found quite useful. For this separation, the value of E_{P_1} is the following at the center of a 7-flare string.

$$E_{P_1} = \frac{I}{h^2} (1 + 2(.83) + 2(.47) + 2(.26))$$

$$= 4.12 \frac{I}{h^2} \tag{7}$$

Increasing the number to nine flares increases the coefficient from 4.12 to 4.42. The increase of almost 30 percent in the number used will increase the maximum illumination by only 7.5 percent.

If a circular path is followed and the sources are again uniformly distributed along it, the illuminance at a point on the ground below the center of the circular path will depend on their number. In the general case, the relation is the following:

$$E_P = \frac{nIh}{b^3} = \frac{nIh}{(h^2 + a^2)^{3/2}} \tag{8}$$

Hence, E_P is the illuminance at P, for a number, n, of sources of intensity I, at the altitude above ground of h, on the circumference of a circle whose radius is a. The slant range from the source circle to P is b. For a radius a = 0.4h, the relation becomes $E_P = 0.8\ nI/h^2$.

d. Location

Not only the level of the illumination but the direction has a strong influence on visibility of a target. This arises from the degree to which long, confusing, deep shadows, or metallic glints from semi-specular surfaces are produced by changes in the azimuth and elevation of the source with respect to the target - observer axis. Typically, studies of the optimum location of the source have shown that it should be in front of, or behind, the target.(53) An advantage of the order of

3x can result from source positioning in either location, which is surely of enough value to justify some effort to secure it. It is possible to explain the location of the optimum source positions a posteriori by noting (a) that diffusely reflected light from the target will be most intense in all cases when the source-target-observer angle is small; (b) that silhouette targets are of maximum contrast and visibility for any given source intensity; and (c) that the glint produced by specular reflections is directed toward the observer when the source is behind the target, or when a small angle exists between the source-target-observer vectors.

In order to utilize these effects, an aerial observer will most often find it desirable to locate the source somehwere near, and behind, him. If it cannot be placed behind the observer, the source must be thoroughly shielded on the observer's side to minimize the interference produced by glare. The change in the state of adaptation of the eye will occur in about 0.1 sec. It is therefore important to avoid even momentary exposures of the observer to the unshielded source. The need for this caution is further emphasized when it is recalled that the discrimination of brightness contrast is a function of the background luminance to which the eye is adapted. When the luminance level is below 0.30 candle/ft^2, the ability to discriminate brightness differences decreases very rapidly. A level below 0.30 candle/ft would be commonly encountered in night reconnaissance.

SECTION IV

TARGETS

1. GENERAL

One of the objectives of this study was the definition of targets which confront aerial observers in the battle area. Under the illumination levels and durations provided by pyrotechnics, a major problem is to distinguish friendly forces from enemy and to identify targets which are of significance. Many targets such as gun positions, materiel dumps, strong points and tanks indefilade are small and are hard to see from the air even during the day. Detection becomes particularly difficult when camouflage measures have been applied and during night operations, which must utilize artificial lighting techniques. The study of target-related phenomena will be organized according to the following definitions. Targets for visual air surveillance are classified as fixed, transient and fleeting:

(1) Any object or structure which is not subject to movement is classified as a fixed target. These include the more permanent military installations, airfields, roads, railroads, bridges, etc. Visual air surveillance missions scheduled for fixed targets are usually supplemented with photo missions or by the visual observer taking photos of these targets.

(2) Transient targets are classified as structures for temporary use. This type of target includes such military installations as camps, bivouacs, supply installations, ammunition dumps and pontoon bridges.

(3) Fleeting targets are objects that move, such as concentrations of troops, vehicles of all kinds, watercraft and aircraft.

In the present study, there is particular concern for targets that are more difficult to acquire due to the associated surroundings (or background) and during nighttime visual tasks. The background associated with land targets consists of the natural terrain including all vegetation and rock formations and soil. These surrounds often blend with the target and render identification extremely difficult during daylight operations under ideal conditions of illumination. Under limited artificial

illumination, and strong contrasts, detection may be practically impossible. The best artificial illuminants suffer from certain inherent disadvantages, such as (1) relatively short duration, (2) moving source, (3) less intense, (4) may cause glare, (5) require accurate delivery, and (6) are not always reliable. Maximum effectiveness in detection of targets under these conditions depends on the visual characteristics and training of the observer, the type, magnitude and placement (altitude) of the light source, the characteristics of target and background and the range and atmospheric condition between observer, source and target. This section is particularly concerned with the relation between the target, the background and detection.

2. PROPERTIES OF TARGETS AND BACKGROUNDS

The principle intrinsic properties of targets and backgrounds which exert an influence on detection are apparent contrast, size and shape, speed (for mobile ground targets) and structure of the field of view. Of those listed, apparent contrast is probably the most important because it is the contrast between target and surroundings that determines whether detection is possible, even at a distance which permits the target to be resolved. At distances so great that the target subtends less than a few minutes of arc, lack of resolution would prevent detection.

a. Apparent Contrast

The apparent contrast, which is a function of brightness, may be expressed as:

$$C = \frac{B_t - B_b}{B_b} \tag{9}$$

where C is the contrast

B_t is the brightness of the target

B_b is the brightness of the background

Increasing brightness reduces the amount of contrast necessary for an object to be seen. Figure 31 shows the relationship between brightness and contrast required to see an object subtending a minute of visual angle. It is clear from this figure that very low brightness (one millilambert) is sufficient to detect a target having a high contrast value, while increasingly high brightnesses are required to see objects

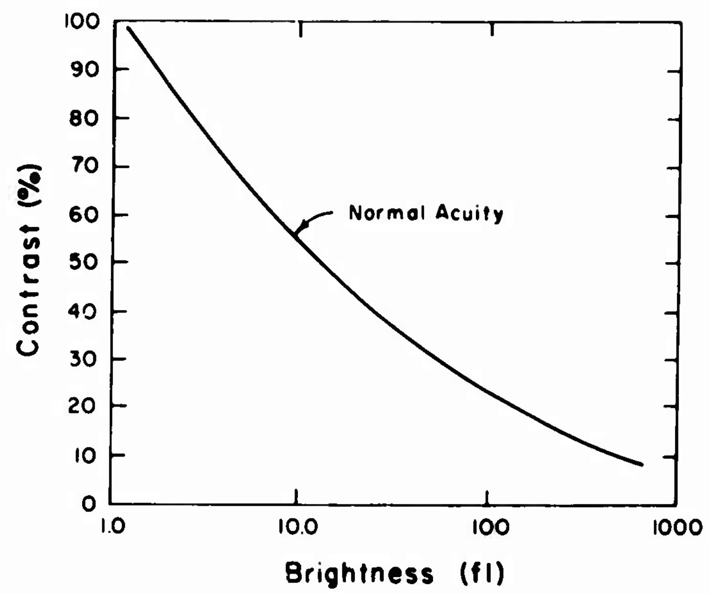

Figure 31. Normal Resolution (of one minute of Visual arc) as a Function of Contrast and Brightness

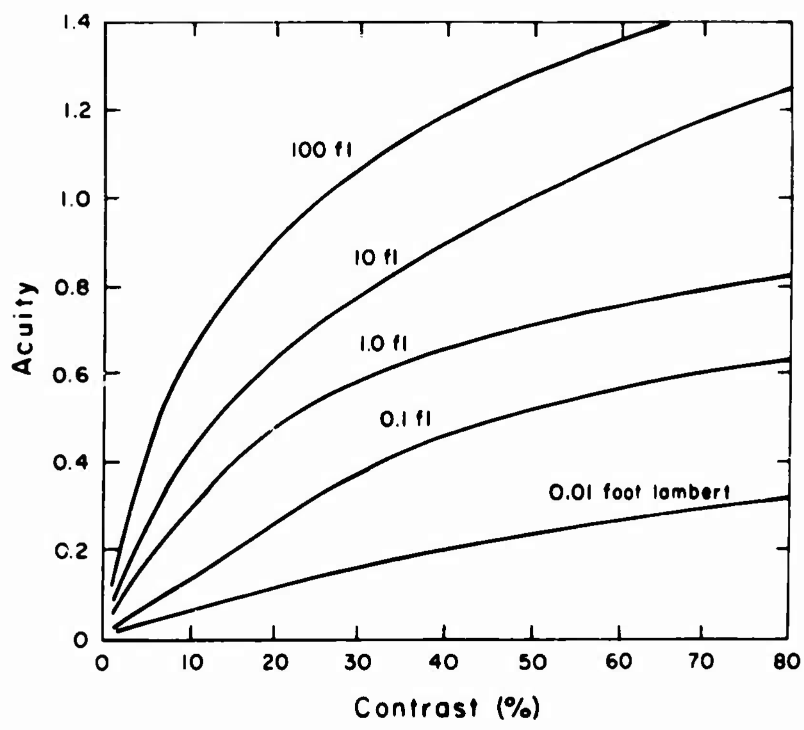

Figure 32. Brightness Requirements as a Function of Acuity and Contrast. Acuity is Reciprocal of Angular Subtense in Minutes

having low contrast with their backgrounds. In order to establish realistic intensity requirements, it is helpful to see the acuity-contrast relationship for various brightness levels. Figure 32 presents this information for brightness levels that might reasonably be expected from pyrotechnic illuminants. In order to more fully appreciate the low level of brightness at which the observer must try to detect targets, consider the average reflectance of the terrain background to be 15 percent to 35 percent. A commonly accepted value for the illumination that can be provided from a flare is 0.10 foot-candle. The effective brightness of the background is thus of the order of 0.02 candle/ft^2 or 0.06 foot-lamberts. At this level, even 100 percent contrast is usually insufficient for certain detection.

At this point certain useful definitions will be provided for reference. The brightness is determined by the spectral reflectance of the material under consideration and the source intensity. Reflectance is defined as the ratio of the reflected radiant energy to the incident radiant energy. The term total reflectance refers to all heterochromatic spatial components of the reflected flux integrated over 2π steradians of space. The radiation reflected from any material surface is composed of two components, specular and diffuse. The specular components of the reflected energy leave a surface at an angle from the normal to the surface which is equal to the incident angle. Obviously, truly specular reflectance can occur only at a surface which is smooth with respect to the wavelength of the incident radiation. In most practical cases, however, the reflected energy will come from a large number of small and randomly oriented surfaces which comprise the aggregate surface. The reflection of the individual rays will be specular, but the entire reflected energy will be distributed over a wide range of angles with respect to the normal from the face of the material; this generally random distribution is referred to as diffuse reflectance.

In order to utilize the formula for contrast effectively, it is necessary to determine whether the target and background reflectances are given as diffuse, specular or a combination thereof. The importance of this lies in the fact that if the target (or background) has a specular reflectance and the background (or target) a diffuse one, relatively low level illumination will sufficiently enhance visibility. Unfortunately, this will occur only for one specified source-to-target-to-observer geometry and is therefore of limited utility. On the other hand, if both are of a diffuse nature, higher levels of illumination will be required, although the geometrical restriction is eliminated. In this latter case,

it is possible to actually conceal a target by blending it into the background through distribution of illumination. The latter case will very seldom, if ever, develop in combat because the backgrounds most commonly encountered are diffuse and the military targets tend to be specular. In almost every case, there is a significant portion of the target having specular reflectance which will enhance detection if the correct observational geometry can be established. Reflectances, of course, will necessarily vary with conditions such as the season of the year, wind and moisture or frost adhering to the vegetation and/or target.

Table VIII (from Dunlap and Associates (59) shows typical reflectance values of various terrain features and building materials. Although the source of illumination, etc., are not indicated, the values show the relative differences in reflectance and give a fair practical indication of brightness contrast that may be expected in the field by inserting these values in the formula given above. The color properties of targets and backgrounds also influence the apparent contrast; however, with military targets where a limited number of drab colors are employed (which are designed to blend with the background) the reflectance value rather than the actual hue is the more important variable.

Quite a number of laboratory and field reflectance and emission measurements have been made by different investigators. Wilburn (57) has reported spectral reflectance, emittance and photometric data in spectral form for a variety of terrain objects, military materials and vehicles. Figure 33 through 40 show the spectral reflectance curves for several military paints and military materials. Measurements were taken with a Bausch and Lomb spectrophotometer with integrating sphere for diffuse and specular reflectance between 0.3 and 0.8 microns. Incandescent lighting was used with a viewing angle of 90°. Olive drab military paints are observed to have reflectances between three and 10 percent mostly diffuse and with only slight differences between the fresh and weathered paints. Total reflectances taken of panels cut from military vehicles were observed to range from under 10 percent to approximately 40 percent.

Extensive daylight reflectance measurements of the terrain have been reported by Krinov (58) under different levels of illumination and seasons of the year. Although small differences existed depending on the type of vegetation, trees, etc., and the time of year, similarities along the spectrum existed among various types which made it possible

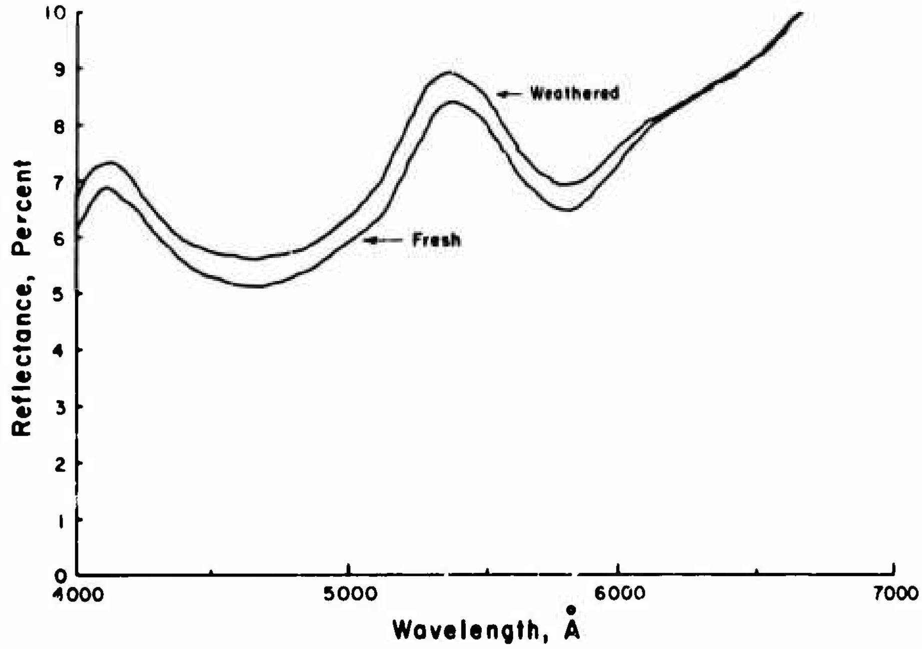

Figure 33. Spectral Reflectance Curve for Diffuse Olive Drab Paint (3-M Co.), Weathered and Fresh

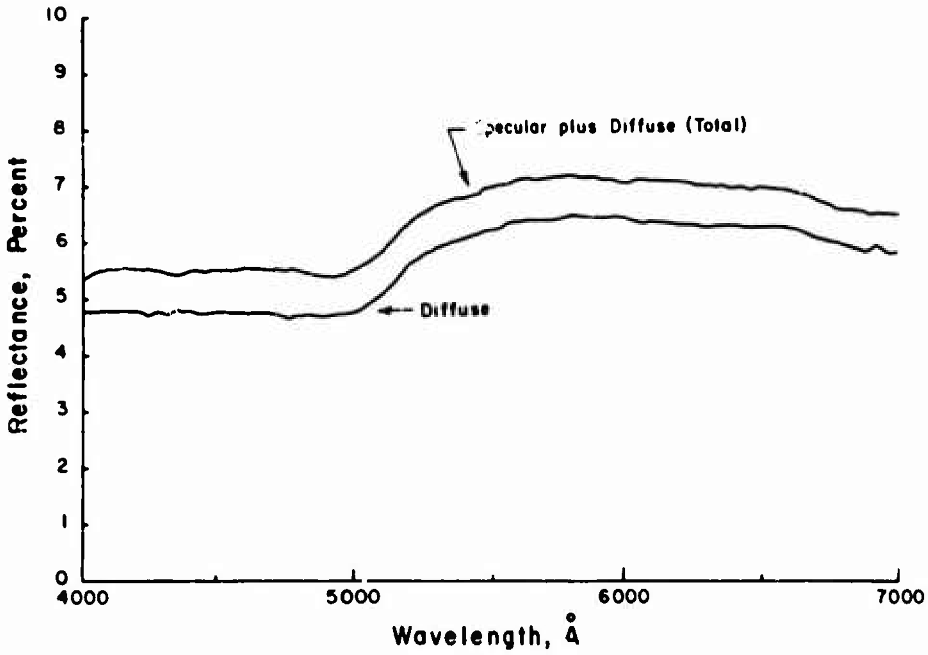

Figure 34. Spectral Reflectance Curve for Olive Drab Paint, Semi-Gloss, Fresh TT-E-527a

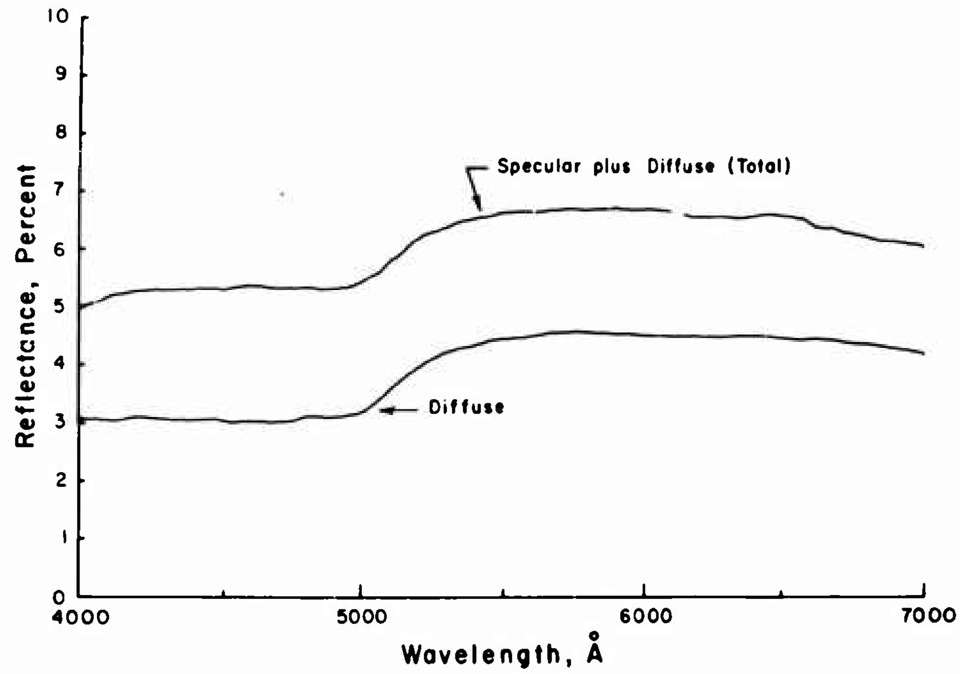

Figure 35. Spectral Reflectance Curve for Olive Drab Paint, Gloss, Fresh TT-E-527a

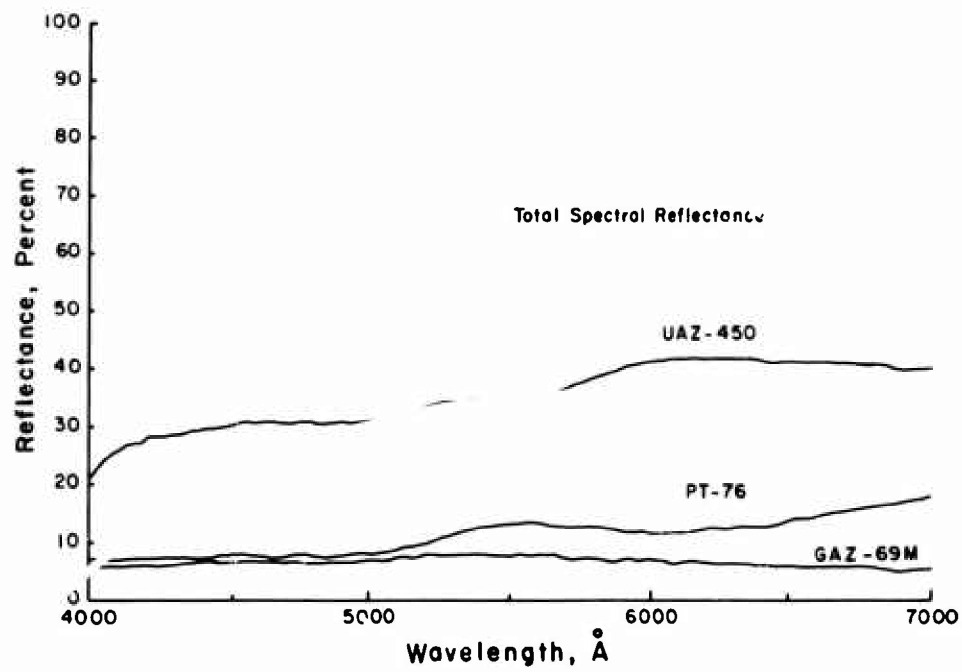

Figure 36. Spectral Reflectance Curves for Painted Panels of Three Russian Vehicles

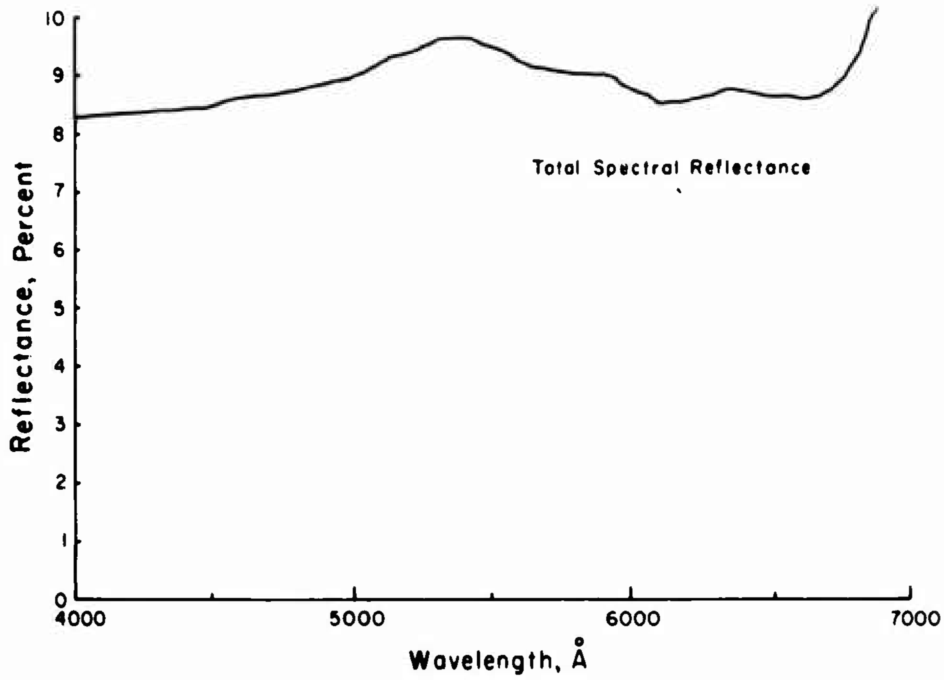

Figure 37. Spectral Reflectance Curve for Fresh I. R. Reflecting Olive Drab Paint, Mil-E-46016

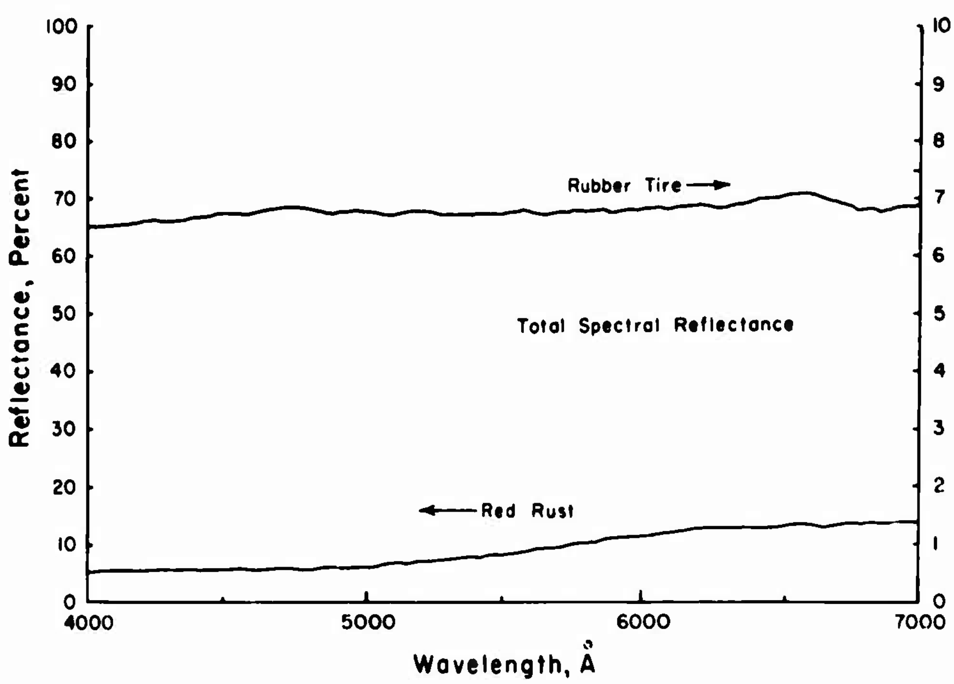

Figure 38. Spectral Reflectance Curves for Red Oxide Rust and Rubber Tire from M-151, 1/4-Ton Truck

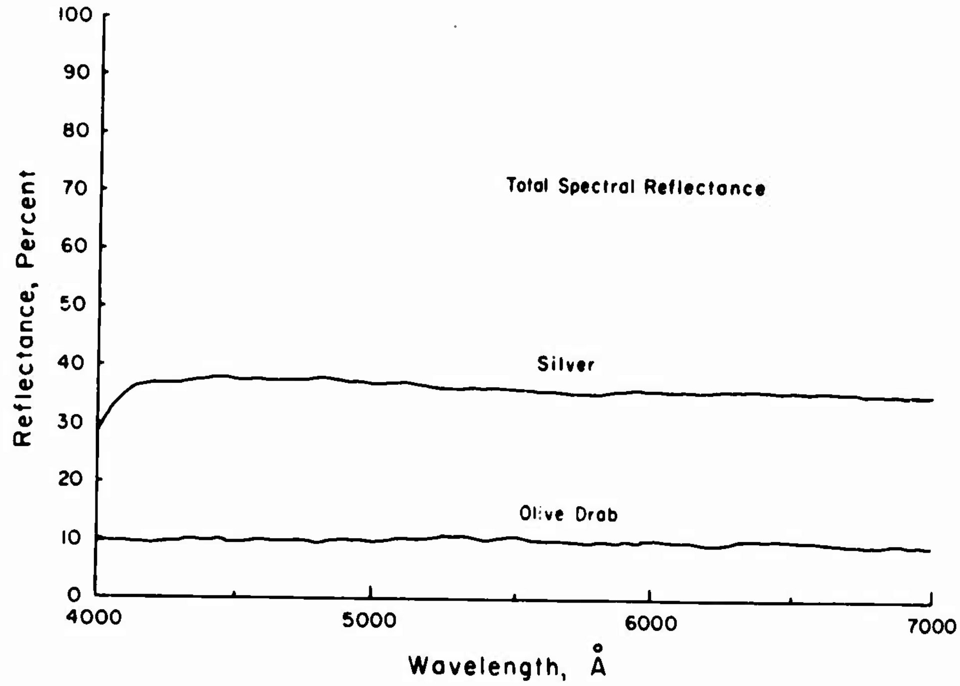

Figure 39. Spectral Reflectance Curve for Mil-C-20696 Nylon Fabric; Olive Drab and Silver Color

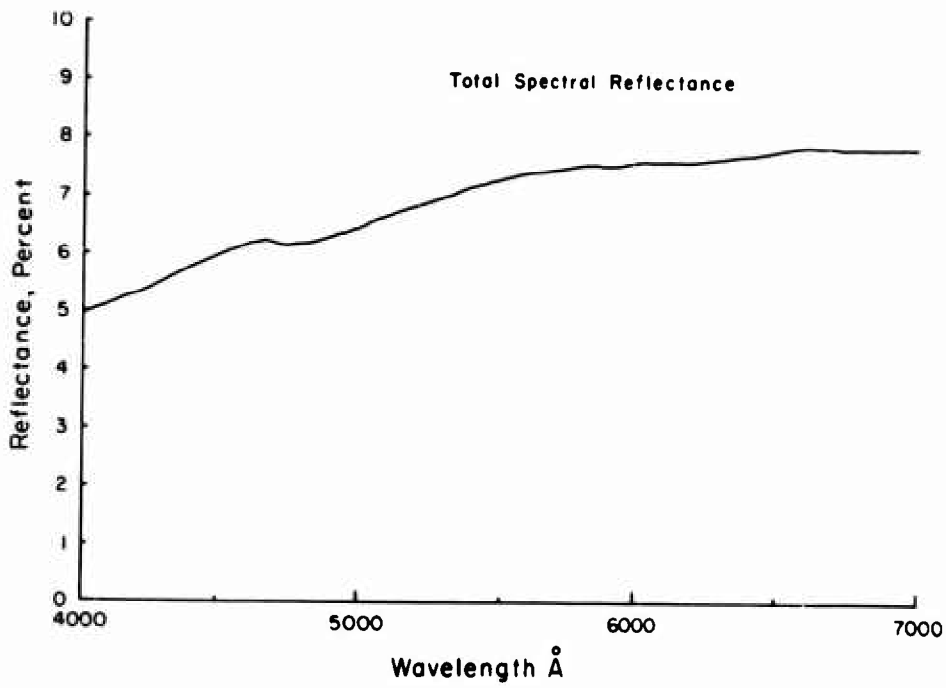

Figure 40. Spectral Reflectance Curve for Olive Drab Canvas

to categorize all curves of forests and shrubs into four groups as shown in Figure 41. Type 1, which shows a very gradual increase in the reflectance curve, corresponds to an almost neutral gray background with a barely noticeable yellowish or brown tint which is typical of all deciduous growth during the winter period. Type 2 curves show a relatively low reflectance level with a weak maximum at about 50 mu. The curves of the second type correspond to a dark green, lightly saturated background typified by coniferous forests in the winter time. The reflectance curves for Type 3 are considerably higher than in the previous case and exhibit a maximum at about 550 mu caused by the saturated color of vegetation. It can be observed that on the average, the reflectance curves of coniferous species are lower than curves of deciduous species. Type 4 curves are similar to those for Type 3 in the lower range of the visible spectrum. Curves of this type correspond to the orange-red background produced in the autumn by all deciduous growths.

According to Krinov, grass-covered areas can be subdivided into two basic groups by their spectral reflectance. One group includes areas whose reflectance curves are typical of vegetation with the usual maximum in the yellow-green portion of the visible spectrum. The other group includes grass-covered areas whose spectral reflectance increases gradually from the violet to the red end of the spectrum. Each group can be divided further into two sub-groups, depending on the nature of the maximum in the yellow-green spectral range and the slope of the curve, respectively. Thus, the curves of grass-covered areas are divided into four types as shown in Figure 42. Data of this type are very necessary for the estimation of target detection. With comparative reflection data for both targets and their associated backgrounds, pyrotechnic light sources can be chosen to produce at least the minimum required contrast between the two and render the target more visible to the observer.

Apparent contrast between significant portions of a target may be improved by adjusting the angle of illumination. This in turn has an influence on detection and identification distance. Experimental studies of identification have been carried out on model simulators.(65) In these experiments, military targets scaled to 1/108 their original size were viewed on a miniature replica of an outdoor scene. The targets were illuminated by a point source of two foot-candles illuminance from positions of 18°, 45°, 90°, 135° and 180° azimuth, 5° elevation. The observer was moved toward the target until he was able to detect it. At

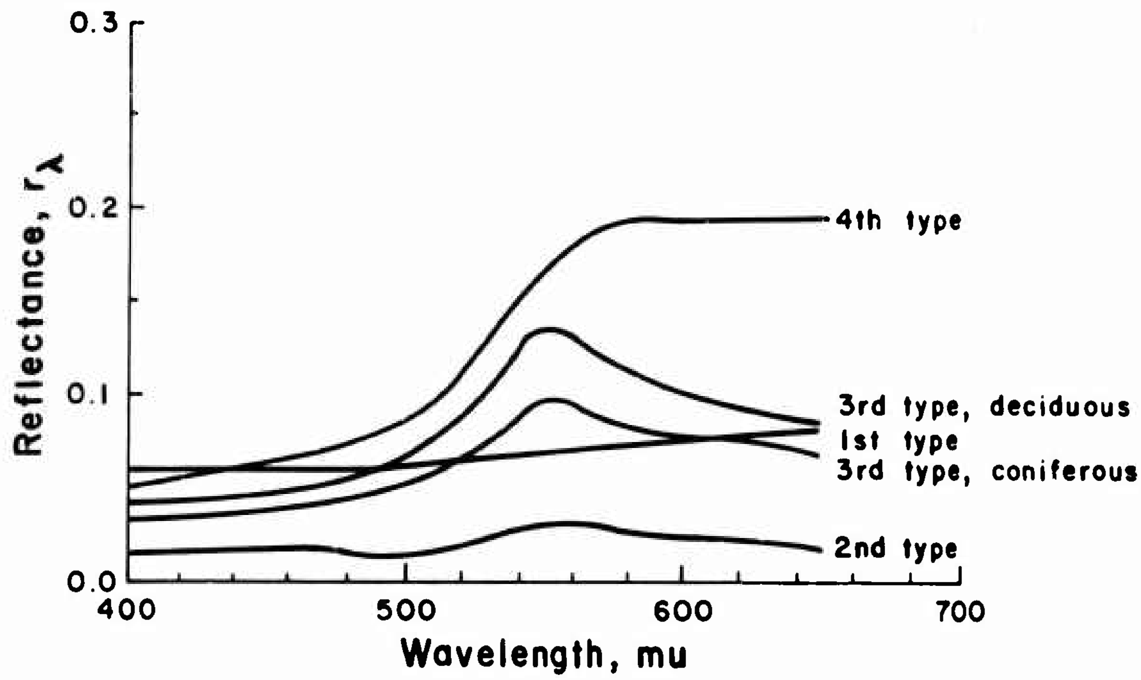

Figure 41. Typical Spectral Reflectance Curves for Forests

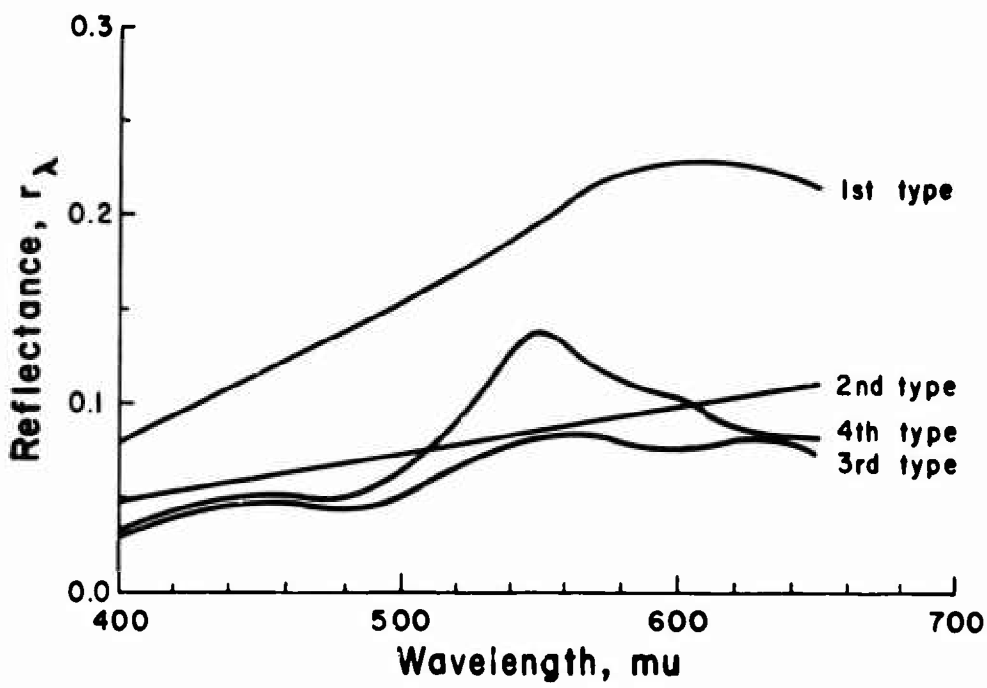

Figure 42. Typical Spectral Reflectance Curves for Grasses

closer distances, he attempted to give class and name designations for the target. The critical "giveaway" feature leading to class or name identification varied somewhat with the position of the illuminant. A small Russian tank was frequently identified under back lighting by a flat area on its turret. Under front lighting, the squatty appearance of the tank was most distinctive. Detection distance for the tank (see Figure 43) one of nine targets included in the study, is larger than class identification by factors of 1.5, 1.4, 2.3, 2.0 and 2.3, depending on source position and larger than name identification by factors of 2.4, 1.6, 2.5, 4.1 and 2.9. Thus, it is apparent that by increasing the contrast of distinctive features of a target, detection and/or recognition may be improved. Model simulator studies of this type often can aid in bridging the gap between laboratory and field studies.

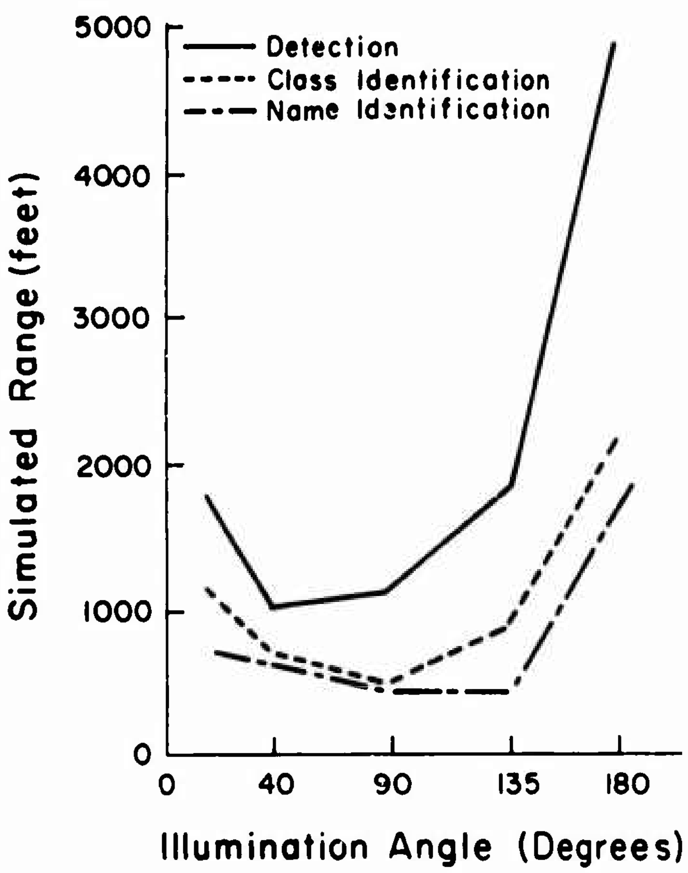

Figure 43. Detection and Identification Distance as a Function of Illuminant Position for Small Russian Tank

The foregoing attempted to emphasize the significance of the apparent contrast of targets and backgrounds in target detection. Most of the data (reflectance, etc.) however has been taken under daylight illumination which, albeit, is very important to target characterization, does not always reflect conditions which may ensue at night under artificial illumination.

b. Size and Shape

It can be generally concluded that the size of a target plays an important role in its detection and the shape in its identification. The size of the target in most cases exerts a stronger influence than does the shape, for it must subtend a minimum visual angle to the eye before recognition occurs. Assuming a constant level of illumination, a fixed duration of exposure, and a single viewing distance, target detection will depend on the interaction between the size of the target and its contrast with the background. The human binocular visual field extends both vertically and laterally to about 130°. Far short of this limiting size, however, it is probable that large targets are not detected in the same manner as targets of moderate subtense. In the usual viewing situation involving binocular search, it is more likely that detection occurs when a target edge is brought onto a retinal area of adequate contrast sensitivity. Small targets require greater contrast for detection than do larger targets.

Under ideal conditions, the threshold size for detection is about 1 minute of arc. This value refers to the greatest sensitivity at the fovea, the central and most discriminating part of the retina. Under field conditions, 3 minutes of arc has been found to be the best acuity for detection that can be consistently achieved. "Line" targets form a special case: A long, thin object can be detected if its width is only one-fifth the above mentioned thresholds. Complex forms appearing on a heterogeneous field must subtend 12 minutes of arc in order to be discriminated (other literature indicates that 20 minutes of arc is a more realistic value for practical work, since it partially takes into account atmospheric attenuation).

When a fixed object is not focused directly on the fovea but appears somewhere in the peripheral vision, the minimum size for detection becomes greater according to the distance from the fovea. The peripheral regions of the retina are not nearly as discriminating as the fovea; therefore, peripheral vision would not be useful for the

ognition process. Figure 44 shows the relationship between the eshold size for detection and angular distance from the fovea.

The effect of target size upon the ease of the detection can be seen in Figures 45, 46, 47, 48 and 49. Obviously, in general, a target is easier to detect and identify when its effective size is increased. It has been concluded by Boynton (60) that for all forms investigated, the probability of recognition increases as the distance to the target decreases. This is essentially increasing the effective size of the target. It was also found that a small increase in size (from 6 linear units to 10 linear units) was found to compensate for a rather large reduction in contrast (from 100 percent to 7 percent).

Target shape is of more importance in identification. It has been found that, under daylight condition at 3000 feet altitude, a tank can be identified; the turret and the gun projecting from the turret can be seen clearly. (68) At 5000 or 6000 feet, the eye loses the ability to distinguish the gun. The shape of the turret can still be distinguished, however, and a tank may still be identified as such. This is especially true if there is enough illumination that the turret casts a shadow which will aid in identification. At an altitude of 10,000 feet, the eye can no longer distinguish the turret and the tank appears as a rectangular object. Similarly, at 3000 feet altitude, artillery pieces can be distinguished. The gun barrel is visible. At 6000 feet as with the tank, the eye loses the ability to distinguish the gun behind the truck.

The compactness of the target appears to be of significance in detection. In a series of laboratory studies carried out at the University of Michigan under the direction of H. R. Blackwell, the effects of target shape on detection were determined for large ranges of other conditions such as background luminance, target size, exposure duration, color and retinal location. In general, the results indicated that circles and other compact figures are easier to detect than figures which are of equal area but are more extended. However, extended rectangles are easier to detect than spatial summation theory predicts. Thus, it seems that shape factors other than compactness contribute to detectability.

Other laboratory experiments have shown that squares and circles having equal areas have also equal visiblity threshold contrasts. Also, a rectangle whose length is 4 times its width and which subtends 25 square minutes to the eye has a threshold increase of 25 percent over

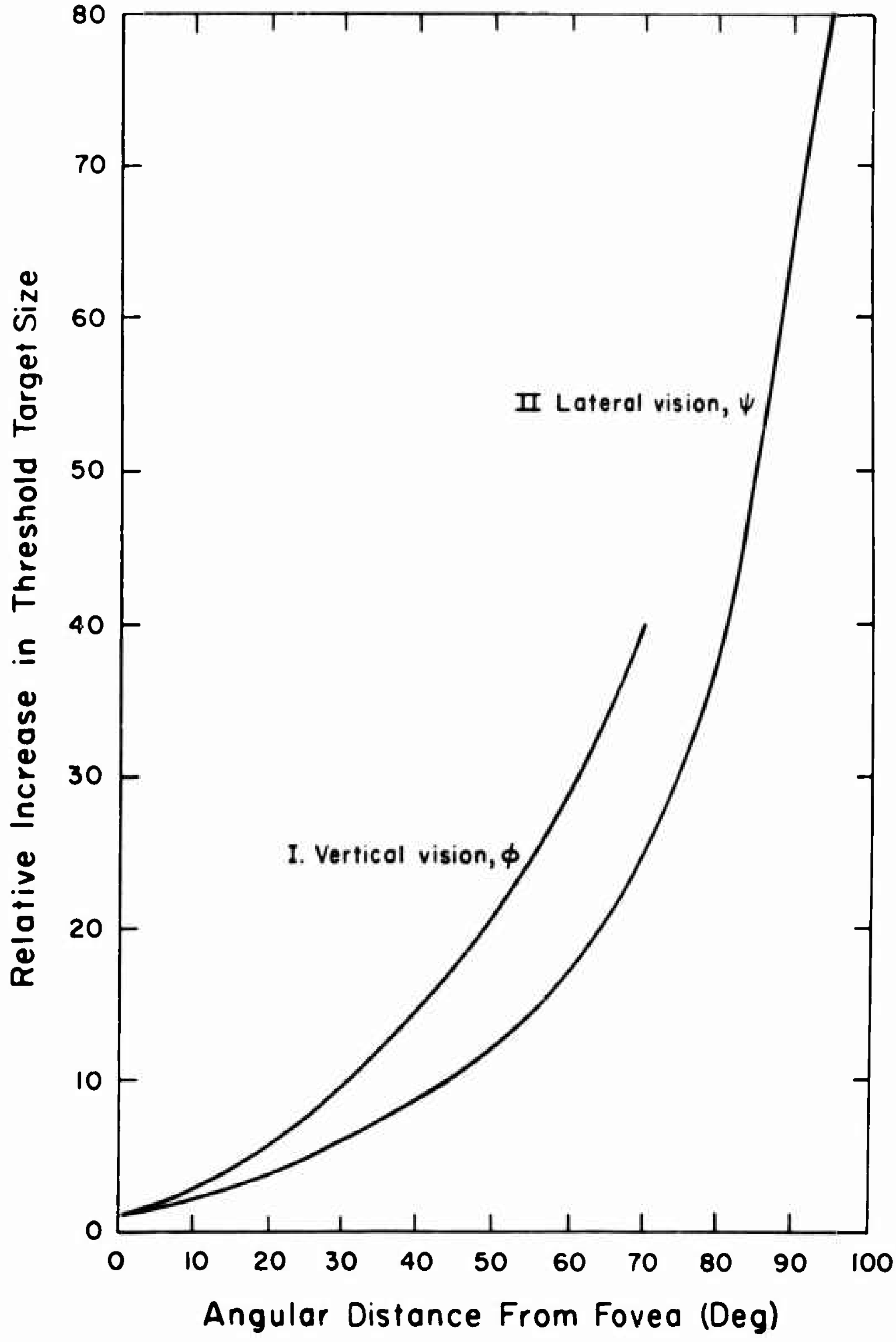

Figure 44. Variation in Threshold with Angular Distance from Fovea

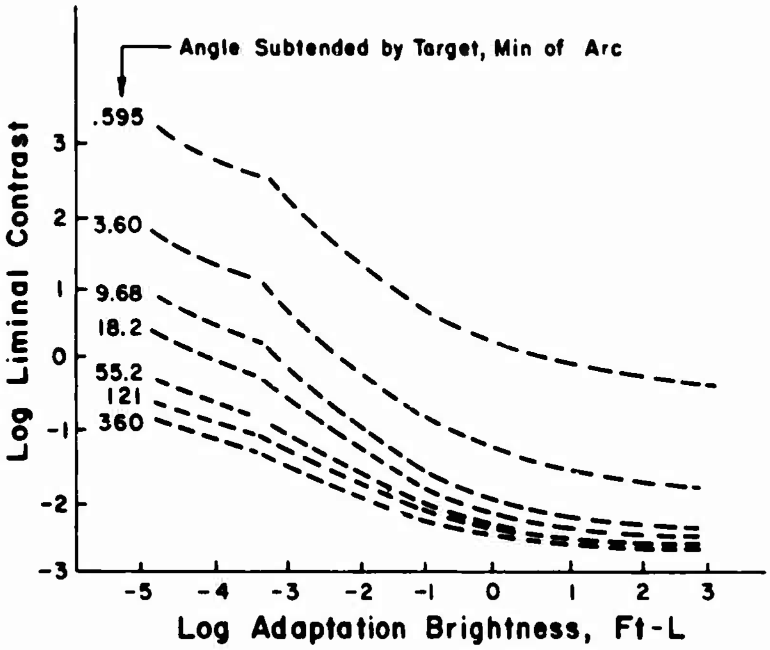

Figure 45. Liminal Contrasts for Round Targets Brighter Than Their Backgrounds. (Target presented in only one position for a sufficient time to attain maximum frequency of correct reports.)

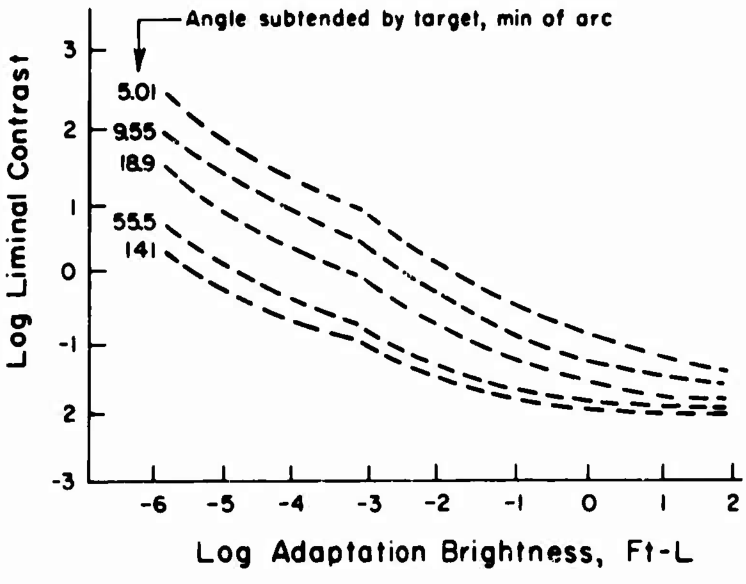

Figure 46. Liminal Contrasts for Round Targets Darker Than Their Backgrounds. (Curves show liminal contrasts for bright targets of the same size)

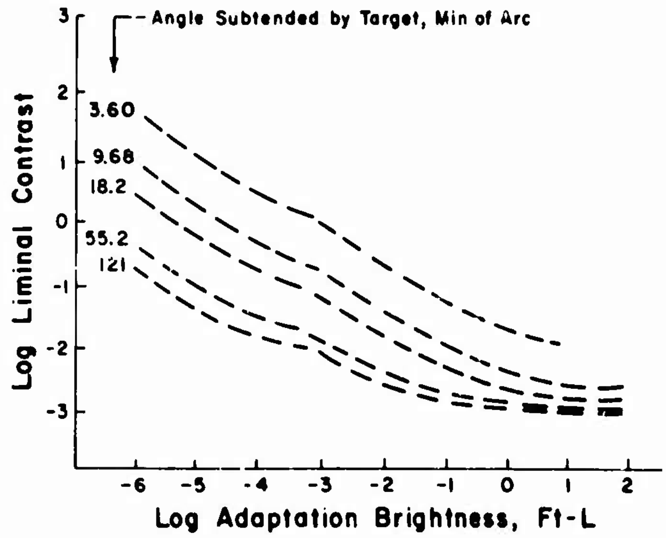

Figure 47. Liminal Contrasts for Round Targets Brighter Than Their Backgrounds. (Targets appeared in one of 8 positions for a 6-sec observation time)

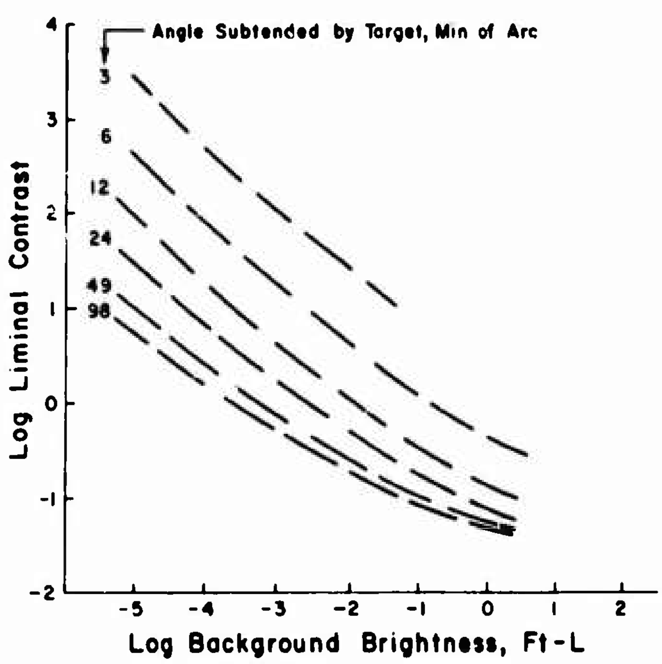

Figure 48. The Upper Bounds of the Liminal Contrasts for Dots and the Landolt Ring. (The actual data show a spread of threshold among different people of about 6 at the lowest luminances to about 2. 5 at the higher luminances)

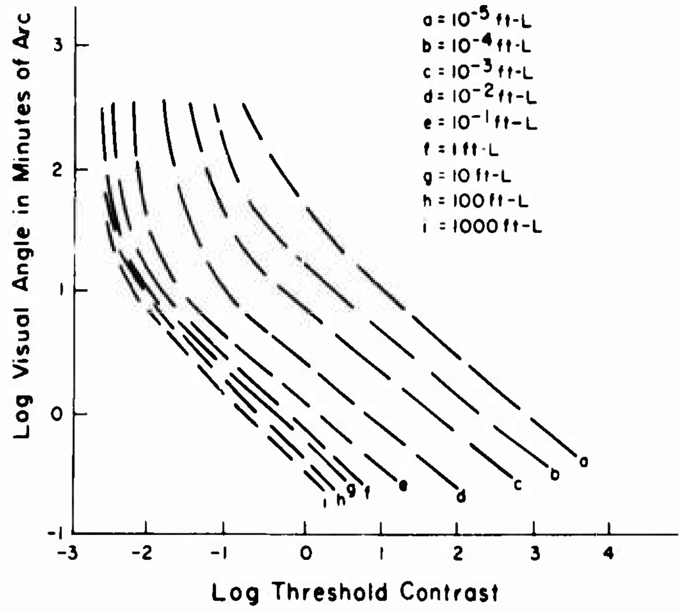

Figure 49. Contrast Discrimination as a Function of Target (Circles) Size and Illumination Level (The linear portion of the curves demonstrate that, for a small source, brightness times area is a constant)

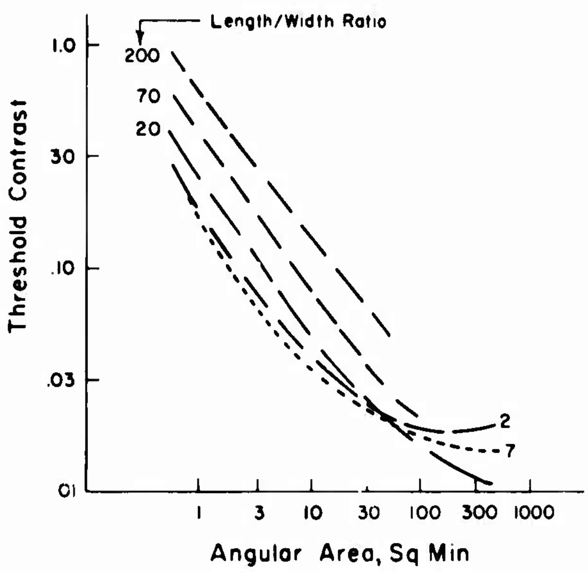

Figure 50. A 3-Sec Monocular Exposure Used With a Brightness of 2,950 Foot Lamberts. (This is about the brightness of a hazy sky at noon)

a square of the same subtended area, that is, the square is easier to detect. The results of experiments using rectangles of various proportions and areas are shown in Figure 50. From these curves, it appears that a rectangle is easier to detect not only when its area is increased but also when its length/width ratio approaches unity, with other variables constant. However, an indefinite variety of shapes is found in the field and the recognition of targets as a function of their shapes (form discrimination) is not well understood. The ability to discriminate any one depends on whether it is viewed by itself or with similar or dissimilar forms. Unfortunately, there appears to be little connection between the physical form and the ability to discriminate form; nor can form discrimination be measured in terms of a standard, in the way visual acuity, for example, is measured.

c. Motion

Moving targets are generally easier to detect than stationary ones. Target-background contrasts will tend to change as the target (vehicle, personnel) traverse a particular terrain. Motion of a target may be perceived by the eye in different ways. According to Klein, (66) there are three types of responses to perceived motion: (1) judgement of absolute velocity of the displacement of a moving stimulus, (2) judgements of relative velocity or displacement in relation to other objects or movements in the visual field and (3) judgements of direction of displacement with absolute or relative velocity. An observer may experience visual movement in several ways: (1) by perceiving the displacement of a moving object across the retina when the eye is fixed, (2) through pursuit movements of the eye across a fixed or moving object, or (3) by induced movement; that is, "apparent" as opposed to "real" movement. Induced movement is observed through the successive presentation of two stationary objects juxtaposed in space or through increasing the brightness of a fixed object.

In many cases involving visual search from the air, moving ground targets will travel at relatively slow speeds and the target may be perceived as moving or movement may be inferred through displacement of the image on the retina in successive observations. During nighttime visual observation, detection may be enhanced through the use of intermittent flashing of the light source and thus "strobing" the target, which causes it to appear at many discrete locations. Detection is enhanced as it is when observation of any slow-moving object - e.g., the minute hand of a clock - is interrupted.

The velocity of the target with respect to the observer will have an effect upon the detection or recognition probability and the tracking accuracy. In a study concerned with the problem of evaluating methods of visual search in low-altitude observation aircraft, the effects of aircraft speed upon search performance were evaluated by Thomas, et al. (61) Figure 51 shows the decrease in performance as the aircraft velocity increases.

It has been found that the error in tracking a moving target in one dimension is directly proportional to the velocity of the target. The results of an experiment described by Garvey and Mitnick (62) indicate that, in general, the faster either a rate (velocity) or an acceleration input, the poorer the performance in a tracking task.

Visual acuity, usually defined in terms of the subjects' response to a static target, has recently been measured using moving targets. (63) It has been found that as the angular velocity of the target with respect to the observer increases, he can see less and less detail. This is shown in Figure 52.

During nighttime visual tasks, motion of a target might be detected through an examination of the shadows produced. Depending on the angle of the illumination, the movement of a shadow could be more conspicuous than the target itself. In many cases, however, target motion may cease (if at all possible) when an enemy suspects approaching surveillance. Personnel, in particular, will not only stop moving but rather easily simulate part of the terrain, making detection very difficult (see following part f). Motion of media associated with the target may sometimes be recognized such as smoke, dust, etc. Under artificial illumination higher reflectances may be associated with clouds of such particulate matter and they may be more easily detected.

In summary, fleeting targets are easier to detect, if the factors of observation distance and angle, aircraft speed, target speed and visibility are within certain threshold limits. In general, movement can probably be most easily recognized when the illumination source is as intense as possible.

d. Structure

The structure of the target has an influence on detection. Work has been conducted by Smith and Loutlit (71) involving the detection of

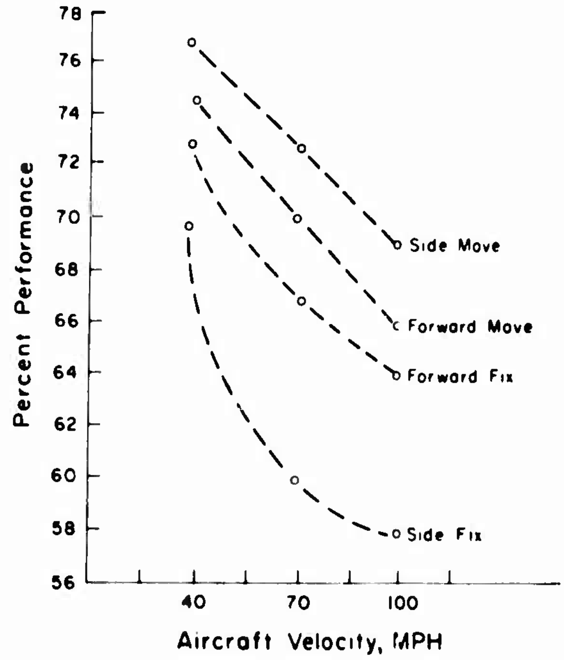

Figure 51. Visual Performance as a Function of Search Methcd and Aircraft Velocity. (Altitude of search, 200 ft. above terrain)

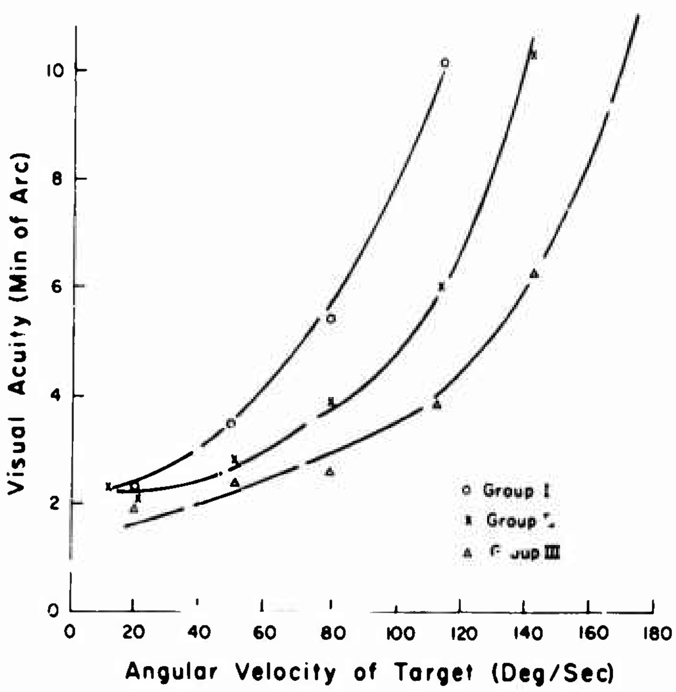

Figure 52. Visual Acuity as a Function of Angular Velocity of the Target. (Three observer groups are shown)

targets with highly ordered elements and those with elements distributed at random. The targets consisted of three sets of different sized elements each containing a grid a checkerboard and two targets with the elements distributed at random. All targets were of equal area and luminous flux. Detectability was compared at different adaptation levels and short versus long stimulus flashes. This study resulted in conclusions that the various target patterns differed in detectability only when they were exposed for a relatively long time at high background luminance. Under these conditions the grid pattern was the easiest to detect and the checkerboard pattern was the most difficult. The random targets were of intermediate difficulty. Thus the degree of organization per se is not a fundamental variable for detection. This study was not meant to reveal the underlying fundamental visual mechanisms involved, however the fact that differences occurred only with high background luminance in combination with long exposure duration and larger elements points to the possible relevance of eye movements, rapid retinal adaptation and reduction of lateral neural spread of excitation. Whatever the important factors may be, it does seem that long straight borders between light and dark areas are facilitative and that studies investigating this characteristic of visual targets are of great interest for detection as well as for search and for other visual functions.

The structure of the target (and the background) can influence the relative reflectances and apparent contrast between the two. Complex background structure will tend to render the target more obscure and more difficult to detect. Generally, however, other characteristics are more influencing on visual detection than structure.

e. Camouflage

Camouflage is probably the most powerful deterrent to visual detection of military targets. If well planned, it destroys the visual pattern (color, contour lines, texture) that makes it possible to detect an object against its background. In many areas of forests or dense foliage, little or no additional cover is required to adequately obscure a target, especially where there is a good blend of colors. These targets are extremely difficult to detect from the air at increased ranges during the daylight hours and virtually impossible at night using artificial illumination. However where additional cover is required, foliage which has been cut off and is therefore dead or dying is commonly used. Detection, in this case, may be possible by searching for its characteristic color, often light brown in contrast to the green of living vegetation.

By inspection of spectral reflectance curves of this dying or dead foliage filters may be selected which are best suited to increase the contrast (and hence the visibility) to the eye or to the camera, of the brown leaves of the camouflage from the green background. It is also possible to use illuminants which radiate in relatively narrow spectral regions to secure a similar effect. It is believed the filtered vision approach is more versatile and easier to implement. Targets without this natural cover (as may be associated with airbases) can be quite effectively camouflaged but, in many instances, may be detected by the well trained observer. In addition, the camouflage is often planned to obscure the target during the daylight hours and the techniques employed (counter-shading, etc.) are influenced by the characteristics of normal solar lighting. In certain cases at night, however, detection may be possible through the correct positioning of artificial illumination in order to highlight tell-tale characteristics. Also it has been known for some time that the reflectance of chlorophyll, for example, differs from imitation camouflage paint. Through the use of adequate filters and, in some cases, light flickering techniques, the imitation may be detected. Light flickering techniques have already been described in a previous section. Other techniques have recently been described by McIntire, et al.,(64) which utilize data on the spectral-directional-reflectance and light-polarizing properties of natural terrain and man-made surfaces. These data show the relationship between reflectance and degree of polarization for non-specular surfaces and reveal how these parameters depend on wavelength of reflected radiation and viewing geometry. If the efficiency of night reconnaissance tasks is to be improved, it appears that the employment of such special techniques is a necessity. In cases where camouflage is complete, target detection may not be possible.

f. Personnel

Without the association of military vehicles, weapons, etc., human targets are very difficult to detect and identify. It is very easy to camouflage them, either by hiding or by simulating objects in the background, even at high contrast. Visual search tests were conducted near Ubon, Thailand, (67) to gather quantitative information on the capabilities of observers in an aircraft to sight and identify humans on the ground. The contrasts (target dress and background) were varied to provide a range of combinations typical of Southeast Asian military and farmer clothing and rice paddy country in the dry season. The task was relatively easy as compared to actual situations because of the lack of

cover. The observers were successful in sighting and identifying the targets in more than 60 percent of their opportunities. The overall slant range appeared to have a fairly consistent value of about 1800-1900 feet over the spectrum of target-background combinations with a 50-ft.-wide search strip. For a 600-ft.-wide search strip, the overall detection-identification range was much less (about 1000 ft.) although this is a less firm conclusion because of the smaller number of runs and because of less accurate simulation of expert observers. Sighting success of the observers in high-contrast conditions without confusing backgrounds was nearly perfect, but even in high contrast conditions, the success dropped markedly when the targets were disposed so as to simulate surrounding objects. A soldier in green field uniform was almost never seen on a moderate background when he stood in contact with bushes. It is numerically clear that a person who knows he is being searched for can simulate a bush or stump and avoid detection without actually hiding.

As described in an earlier section, (Section II-3-g) due to differences in reflectance between military clothing and green foliage some advantages might be realized through the use of special techniques using a flickering light source. However, in visual search from the air it would probably be more fruitful to concentrate on larger targets to reveal enemy activities.

3. SUMMARY

The various peculiarities of targets that have been found to influence detection have been described in this section. Unfortunately many of the characteristics discussed cannot be considered independently as it is a combination of variables concerned with not only the target and background but with the aircraft environment, the observer, the illumination and the visibility that govern detection. A considerable number of studies have been conducted in the laboratory and significant correlations among some of the variables in visual detection and recognition have been established. Most of the laboratory and simulator results have not been verified in the field, however. Isolated attempts to verify laboratory results in the field have not met with great success. One of the problems, as mentioned above, in these studies is the large number of critical variables involved. The laboratory studies for the most part have been carefully controlled experiments in which only a small number of parameters were varied. In some cases the studies are applicable in the field, however it should not be assumed that this is

the rule. The military observer is said to "detect" when he senses an object of military significance. The object is not a uniform disc seen against a homogeneous background, but a three dimensional tank, weapons carrier, jeep soldier, etc., seen against natural forms and textures. The background may be smooth or present various degrees of texture. This detection is more properly a type of identification - an identification that the object is not a textural detail of ground, foliage, sea or sky, but rather something unusual, man made, and not usually seen in that location. Often, position, time and type of previous action are contexural, nonvisual elements of information which aid military identification by permitting deductions to be made. In Korea, glints of light were identified as tanks because of their location. Field tests are, thus, hard to simulate in a laboratory or model.

The field test is not without its disadvantages, however. They are usually difficult to carry out and costly. Changes in illumination (which can occur at night during a field test) may reduce visibility distance to less than half and changes in foliage color as summer turns to fall will also affect visibility. (The latter change introduces a variable when tests are duplicated during different seasons.) Model simulator studies can be quite useful because they can be carried out under closely controlled conditions. The illumination and viewing conditions are "frozen" for sufficient periods of time to permit psychophysical measurement Problems of logistics and the moving of men and equipment do not arise. The most effective approach to visibility problems would involve a combination of laboratory, simulator and field experimentation. In laboratory studies the relationship between variables may be and has been explored over a wide range. Theory may be developed which permits simplification of field and simulator research and allows prediction to a wide variety of situations. Simulator research is useful for determining the relevant variables, and solving problems requiring psychophysical observations in a natural setting. Finally simulator and laboratory results should be checked for validity in field experimentation. It is the last two stages of investigation which at present appear to require a great deal more emphasis.

The target and background properties that exert an influence on detection have been described in this section, however it is felt that many situations will be near the threshold level. In the final analysis, then, as pointed out earlier, the ability to detect a target will depend on the observer himself; on his training, his previous experiences and information and on his physical and psychological characteristics.

SECTION V

SUMMARY AND CONCLUSIONS

1. GENERAL

When this study was begun it was known that a number of extensive studies had been made with, generally, the objective of establishing criteria for the prediction of target detection. A large amount of data on illuminating (and incidentally signalling) pyrotechnics was also known to exist, albeit somewhat scattered and hard to obtain. If all the relevant materials were to be brought together and evaluated somewhat concurrently, a summarization could be attempted. The resulting digest would allow the field observer to select a flare and determine his optimum position with regard to the source and target for a maximum detection probability. The selection would be made on the basis of known characteristics of the target and background regarding color, reflectance, size and mobility. With these values as parameters, a range of flare source sizes, durations and possible positions relative to target and observer could be examined and the selection based, finally, on the uncontrollable tactical requirements. All of this was based upon the assumption that not only a large amount of data were available in the literature but that they were of the right form and kind for this approach to be useful.

As a result of the search of the literature that was conducted to implement the creation of such a digest during this study, many hundreds of articles dealing with various aspects of the phenomena involved in seeing an object were examined. It was then discovered that the great bulk of the literature dealt with investigations of rather fine details in the vision process. For example, the titles of several articles examined are as follows: "Neural Formulation of the Effects of Target Size and Shape Upon Visual Detection"; "Adaptation in Color Space"; "Visual Resolution as a Function of Intensity and Exposure Time in the Human Fovea"; and "Visual Discrimination, An Interpretation in Terms of Visibility Theory." Some reports dealt almost exclusively with neurological or physiological detail. All of these reports represent the efforts of some investigator(s) to improve our understanding of the extremely complex process by which the human eye and brain in combination operate to detect and recognize objects. Unfortunately, in spite of these efforts the steps by which, for example, the hunter sees and identifies a deer standing in the edge of a woods at twilight still elude an engineering description.

The visibility investigations conducted by several fine research groups are recognized for the contribution that they make to the understanding of the means of target detection in practice. The Visibility Laboratory of the Scripps Institute of Oceanography; the University of Michigan Working Group on Surveillance Sciences; the National Research Council Committee on Vision; the Human Resources Office of George Washington University and the historic Tiffany Foundation, have made tremendous contributions to visibility and target detections. Nonetheless, it still remains very difficult to apply much of the results of these studies to a common practical problem, such as determining the minimum illumination of a battlefield in order to obtain a high probability of detection of some specified details. It should be noted that related problems occur in areas such as highway designing for maximum safety. The laboratory measurements of visual acuity in terms of Landolt "C" targets, brightness discrimination, etc., are reasonably quantitative in the results they produce and a part of the detection and recognition process can therefore be described quantitatively in terms of the results obtained from such tests. Other equally important factors are not so characterized, e.g., form recognition, or pattern recognition as it is called in many current studies, which is essential to recognition of a detected target. Color perception is not understood a great deal better than form recognition and is equally necessary in many cases. Thus it appears that in spite of the tremendous amount of money and effort that has been spent on these problems, the material needed for engineering solutions is not yet within our grasp.

It has, therefore, been necessary to present a summary of the parts of many studies that have appeared to be useful in connection with the application of pyrotechnics to night vision problems. In addition, the need for work to supply missing information is pointed out wherever it has been apparent. Finally, the results from experiments performed during this study are discussed with the purpose of adding a bit of knowledge regarding detection of colored objects. The relatively large number of references obtained from a variety of sources have been included in the form of a bibliographical appendix. In addition, the information obtained regarding parameters which characterize illuminating and signalling flares has been assembled in several appendices for reference. The result is a step in the direction of the kind of digest that was thought to be possible at this time. Much more work is needed, primarily in terms of visibility studies, before it can become a reality. Because a summary of the kind presented in this report may be called upon to serve a variety of purposes, a number of plots and tables which

may aid the user have been placed in an appendix. These give ranges of values for variables of interest, conversion factors and similar generally useful information.

2. OBSERVER

The description of the processes which occur in seeing by a normal subject is the weak link in the design of illumination systems for military uses in reconnaissance actions. The steps which occur following entry of light into the eyeball are extremely complex and interlocked in the relation between one effect and another. In military reconnaissance, it is expected that an observer, under stress, in surroundings that allow little time for deliberation, will detect a small target that often is deliberately obscured and which is located against a variegated background. It has been stated during a discussion that some evidence has been found for a 10 X to 100 X increase in the illuminance level required for a given task when the subject is under extreme stress. It has not been possible to find the source of this claimed effect, but it does represent another complication that will be present to some extent in these reconnaissance situations. In contrast, the studies which have been made of the processes of vision are conducted under ideal conditions. That is, the subject is under no stress from a fear of being injured, the surroundings are comfortable, the targets are not obscured, only one decision is involved in a given test, etc. It is not really surprising that the results obtained from these tests do not lend themselves to direct application to the preceding situation. In other words, when the observer "sees" a target he is using several abilities simultaneously. He is not just discriminating a brightness difference or an edge or a color but is processing all these kinds of information more or less simultaneously. If data are taken which are obtained in a way that minimizes all but, say, one of these inputs, the application of that data to reality is difficult if not suspect. It appears that what is required is more well-simulated field reconnaissance tests, albeit the emotional overtones may not be simulated, to develop essentially empirical rules. These rules would provide the basis for predicting what illuminance levels would be required on a target area of, say, sand and desert brush, to first detect and then identify a camouflaged tank from a slant range of 3 miles and 3000 feet altitude. Tests of this kind could be conducted in two stages. First, the rules would be established with highly realistic terrain models and a large number of observations. These should be verified by actual field tests of the predicted visibility, in a lesser number but still adequate for statistical significance levels to be established.

None of the foregoing is to be interpreted as a criticism of the work that is being done to unravel the visual processes by laboratory studies under optimal conditions. These studies will in time produce an excellent description of all of the processes involved in seeing. When this has occurred, a computer can be programmed to give just exactly the answers required for any set of circumstances, including allowances for biological variations from the assumed norm. However, the time when this may occur must be many years in the future. In the meantime, military problems will continue to demand answers and it is these answers that may be obtained empirically, since the intent is not to explain, but to produce a needed result. Studies of this general class have been made but they have not been comprehensive or extensive enough to accomplish the task. (AD 213 409, AD 468 244, AD 118 250, AD 415 687, AD 468 749, AD 459 488, AD 251 823, AD 231 629, AD 468 930, AD 294 599, AD 295 630 are typical examples of such studies.) It is suggested that an effort be made to establish an experimental program of exploratory development type to design the experimental work that would be required to obtain empirical answers to the problems of night reconnaissance.

In the meantime, the estimation of required levels of illumination may be based upon the data given in this report. It should be realized that these estimates will not be of great accuracy because the totality of influential factors are only partially incorporated.

3. SOURCE

The characteristics of pyrotechnic sources which determine their suitability as illuminants or signals have been summarized in Tables XIV through XXI. The data have been obtained from many sources and vary widely in the degree to which all of the values are reported. When a missing value could be calculated from the data that were available, this was done. If the data given were obscure - e.g., weights that could refer to the pyrotechnic mix only or to the total weight including casing - the missing values were not computed. The sources have been identified for all data reported. In connection with problems of illumination, the data in Tables XV and XIX will be of the greatest interest. It will be obvious that few data exist on the color, color purity, cp/in^2 and $cp\text{-}sec/in^2$. In some cases so few entires were made that the characteristic would not have been listed save for the use of the same tabulation scheme for all of the flares, colored signals as well as illuminating flares. A range in candlepower (candela) from 9.0 to

7.8×10^6 is reported, with most of the values ranging from 50,000 to 500,000. The range of candlepower-seconds per gram extends from about 20,000 to 90,000, most values lying between about 40,000 and 80,000. The spread of these cp-sec/gm values indicates the severity of the measurement problem in making these determinations and the need for improvement in methodology. From the work reported in the literature, the best composition for use in illuminating flares under ordinary conditions is magnesium-sodium nitrate. This is solely on the basis of output, safety under impact and other operational problems excluded. Although aluminum should produce a greater illuminance per gram, it does not do so in practice. All evidence considered, it would seem unlikely that any better substitute for the magnesium-sodium nitrate composition will be found, as long as flares are made from pressed mixtures of solids. Current research in the properties of cast flares is being conducted by Thiokol and Ordnance Research Incorporated: It appears that these compositions may produce some improvement in the illumination obtainable from a given volume of material. Improvement in efficiency appears to be possible if effective means can be found to decrease the radiation from solids in the flame and increase it from species radiating in useful regions. Some promising work has been done in this area at the Denver Research Institute under Navy contracts. The radiation from these compositions was of greater purity and intensity than is produced by the customary red and green signal compositions. It should be as effective in producing essentially white light.

The competition from non-pyrotechnic sources of illumination is increasing. Technological improvements in the generation of electrical power and electrical light sources may soon make them the illuminants of choice for long missions. Chemical sources of a non-pyrotechnic nature are being developed which may also displace them for long-duration applications requiring moderately high levels of intensity. Study of these other sources has not formed a part of this task but the information above is included to insure that the best source for a given task may at least receive consideration.

4. TARGET

The most important characteristics of the target, from the detection aspect, are its angular size and its contrast with the background. Color is important insofar as it relates to contrast effects, e.g., yellow against a dark background, but most targets of military interest have been treated to minimize and suppress color contrasts. A moving target

is more readily acquired by peripheral vision and thence transferred to the foveal area for detailed appraisal. However, motion is suppressed for this very reason and cannot be depended on as an element of the detection process.

Therefore, the target parameters on which a visual detection method should be based are size and brightness contrast with improvement in detectability because of color or motion considered as unexpected benefits. The level of adaptation of the eye affect the absolute magnitudes of size and contrast at which detection is possible, as noted in Section II. Some degradation of these limits will occur when the meteorological conditions are bad. It would seem to be unlikely that a visual reconnaissance would be undertaken in the face of bad visibility. For this reason, little consideration has been given to the effects of haze, fog, rain, etc.

The information which is required to describe a target and the background has been developed rather extensively. From these data certain average values may be obtained which are more useful in practical field situations than the detailed listings are. The latter listing could be used in a computer program which would evaluate a given mission and produce an optimum set of values for the observational parameters, but it is of little use in a manual evaluation, unless considerable time is available.

5. SELECTION

A choice of illuminant is possible by different computational routes, depending upon the information available. The following method is suggested as an appropriate one to illustrate the process. Is is not claimed that it is highly accurate for the reasons that have been presented throughout this report. However, it does represent an attempt to make use of the data available from the many studies conducted and thus perhaps more effectively point out the work which is needed to place visual night reconnaissance on a quantitative basis.

It will be necessary to make some assumptions in the development of this illustrative example. These will be stated as they are required. The first assumption - not always valid - will be that the type of target sought is known; e. g., an object such as an olive drab painted tank with a major surface element of 20 square feet area measuring roughly 3 feet by 7 feet, and that this object is located on dry sand.

a. First Step.

From a table such as Table IX, determine the total diffuse reflectance of the target. For olive drab paint, this is given as 8; i.e., 8 percent. Find the reflectance of background also (in this example, 25).

b. Second Step.

Calculate the inherent contrast, which is done on the assumption that the luminance is directly proportional to the total diffuse reflectance. It would be more correct to use an average luminance factor for this purpose, but this is not generally available for the materials of military interest. A detailed discussion of this matter; i.e., luminance factors - may be found in Walsh.(69) In this example,

$$C_I = \frac{8 - 25}{25} = -0.66$$

the negative indicating only that the target is darker than the background and will probably appear in silhouette. The common logarithm of this value 0.66 is -0.18.

c. Third Step.

From the target dimensions calculate the target area, A_T, and the length to width factor, F_R. A value of F_R greater than about 7 should be avoided, because the effect of shape is unimportant at or below this value.

d. Fourth Step.

Decide on the range at which it is desired to see, that is, to detect the target. For this example, a range of 3000 yards will be chosen.

e. Fifth Step.

Compute the angular subtense of the target. Units are not of importance but minutes of arc are convenient.

$$\theta = \frac{A_T \times 10^4}{3 \times \text{range}} = \frac{20 \times 10^4}{3 \times 9000} = \frac{200}{27} = 7.5 \text{ minutes}$$

The common logarithm of 7.5 is 0.875.

f. Sixth Step.

If there were no atmospheric effects, the values formed thus far could be used to enter Figure 53 to obtain a value for the background luminance required and from it the illuminance needed. However, the only result of including the remaining calculations will be to increase the intensity required at the source for a given set of conditions. It is therefore of interest to enter these values in Figure 53 and determine the luminance it would require. If this value is greater than can be obtained, there is no need to proceed with the next set of calculations. When this has been done, the value of the adaptation luminance is seen to be 10^{-2} candles meter^{-2}. Because the sand reflectance is 0.25, an incident flux will be required at a level of at least 4×10^{-2} meter candles, or $4 \times 10^{-2}/10.76 = 3.7 \times 10^{-3}$ foot candles. This could be obtained from a source of intensity, I

$$I = R^2 B_H = (9 \times 10^3)^2 \times (3.7 \times 10^{-3}) = 3 \times 10^5 \text{ candlepower}$$

which is obtained readily from modern illuminating flares.

g. Seventh Step.

Figure 54 is now entered to find the liminal apparent contrast required for detection at the chosen range. Note that Figure 54 is drawn for a background luminance of $B_H = 10^{-2}$ foot lambert $= 3.2 \times 10^{-3}$ candle ft^{-2}. This is the nearest value for which a nomogram is available. Find the intersection of the (vertical) range line with the appropriate target area curve. A line, A, from the infinity value on the left ordinate through the intersection point will intercept the right boundary ordinate at a point indicating the required liminal apparent contrast. (70) It is seen to be 1.85, in excess of the value of C_I by a factor of almost three. Line B may be drawn from the infinity ordinate to C_I on the contrast scale and at the 3000 yards ordinate it will be seen that the intersection is near the 60 ft^2 target area curve. The assumed target is not detectable at the proposed level of illumination, but one of three times the area is. At this point, in practice, a reevaluation would be required. By examining the nomograms of the type in Figure 54, one can find a condition which would permit detection of the 20 ft^2 target. A suitable nomogram is shown in Figure 55 which is constructed for a value of $B_H = 10$ foot lamberts; i.e., 3.2 candle ft^{-2}. To obtain this level, a source producing $3.2/0.25 = 12.8$ foot candles at, say, 3000 feet is needed.

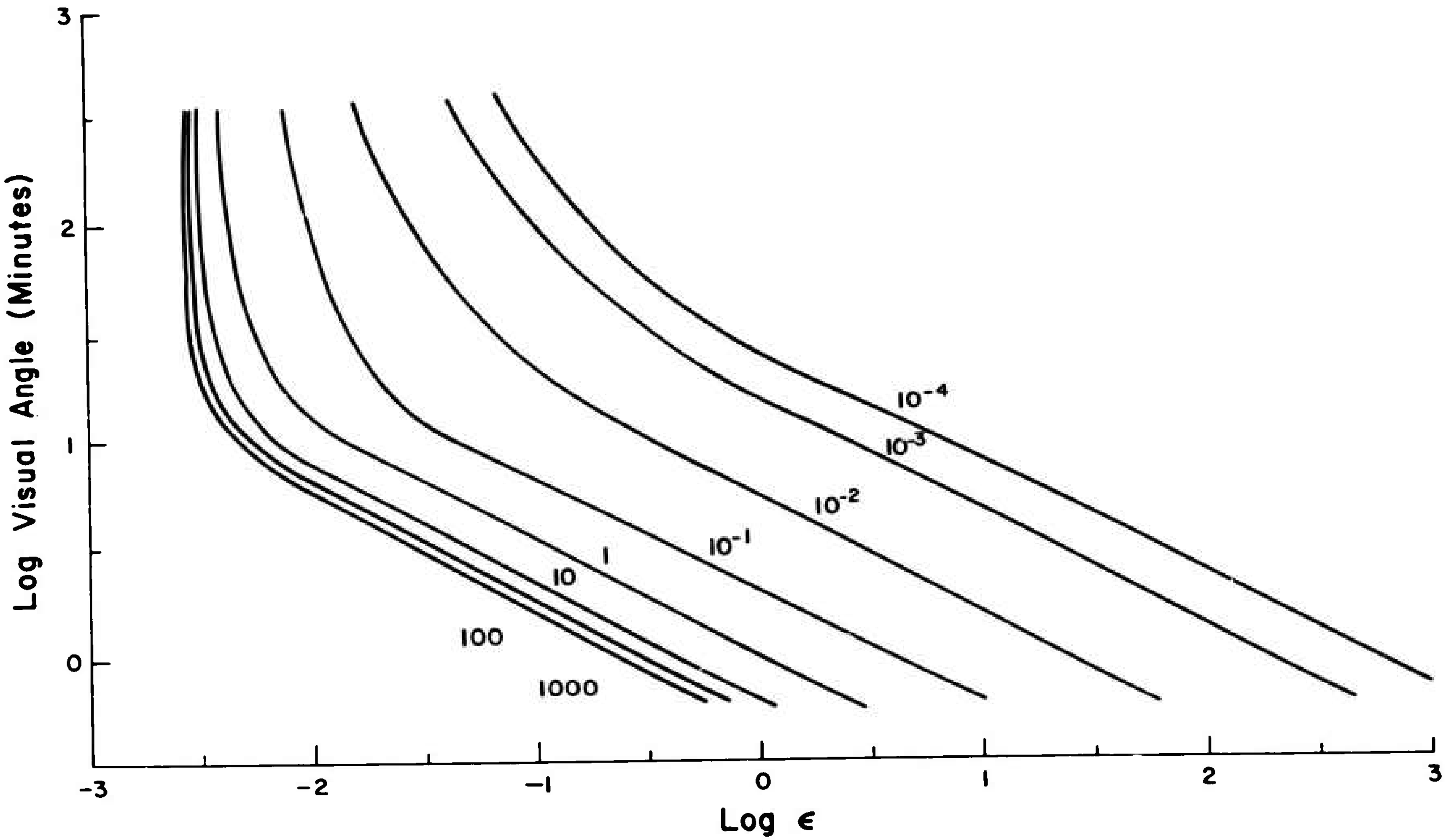

Figure 53. Liminal Size vs. Contrast Required at Several Levels of Adaptation Luminance (candles meter^{-2})

Figure 54. Nomogram to Solve Target Size - Contrast - Range Relation at a Luminance of 10^{-2} Foot Lamberts. From Duntley (70)

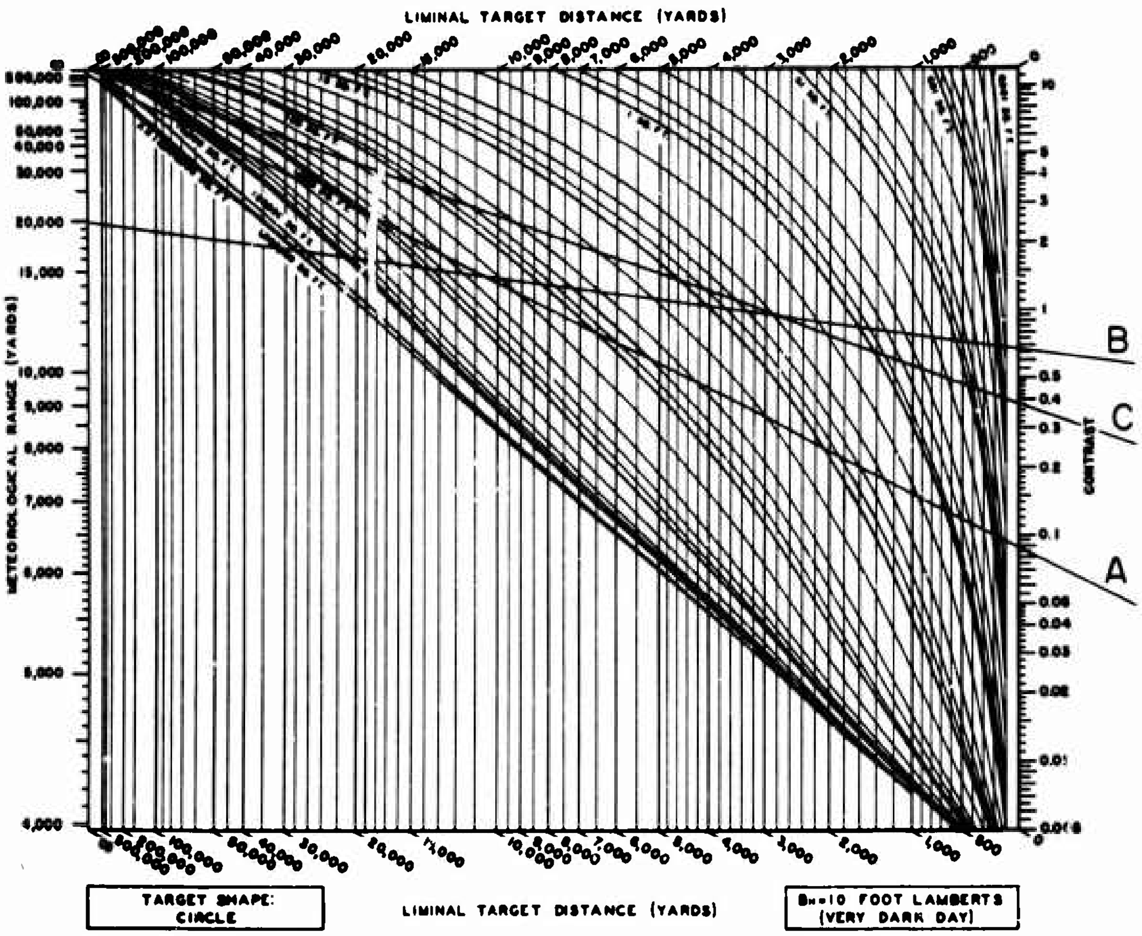

Figure 55. Nomogram to Solve Target Size - Contrast - Range Relation at a Luminance of 10 Foot Lamberts. From Duntley (70)

$$I = 12.8 \times 9 \times 10^6 = 115 \times 10^6 \text{ cp}$$

No pyrotechnic flare of this intensity is now available; however, for purposes of illustration the example will be continued as though it were. From Line A on Figure 55 the liminal apparent contrast is seen to be 0.09, well below the inherent contrast of 0.66. Assuming atmospheric conditions which produce a meteorological range of 20,000 yards, Line B is drawn from this value to the inherent contrast value, $C_I = 0.66$. A line from the infinity ordinate through the intersection of Line B with the 3000 yard range line is drawn, Line C, which intersects the contrast ordinate at 0.38. This is the apparent contrast value at this range. It is well above the liminal value of 0.09 and it may be assumed the target is detectable when the background luminance is 3.2 candle ft^{-2} (or more)

h. Eighth Step.

Finally, the range may be calculated at which the 3.2 candle ft^{-2} level may be produced from available flares. In Step 7, the illuminance required on the ground was seen to be about 13 foot candles. The largest flare currently available produces about 5×10^6 candlepower. Thus,

$$R = \frac{5 \times 10^6}{13} = 40 \times 10^4 = 6.3 \times 10^2 \text{ feet}$$

is the maximum distance from this source at which an illuminance of 13 foot candles can be produced.

i. Commentary

It is evident that these calculations are based, primarily, on the work of Blackwell and Duntley, published in various papers prior to 1950. A simplified approach has been adapted in this application of their results in the belief that great accuracy is not warranted by the available values used in the reflectances, limits of resolution, etc. No allowance was made for the increased level of illuminance that would certainly be required in combat operations. This requirement arises from the psychological stress, the short times available for visual search and the loss of night vision which results from inadvertent sightings of muzzle-flash from guns, flares seen directly, burning targets,

etc. The result of allowing for these effects would be an increase in the candlepower of the source. The amount of increase can only be guessed, but it would be of the order of five times at least.

SECTION VI

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Office of the Chief of Research & Development
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APPENDIX II

TABLES

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TABLE I. ART PAPERS USED IN FLICKER EXPERIMENTS

Color	DRI Sample No.	Approximate Munsell No.	Federal Standard MIL 595
Brown	2B	5 YR 4/5	20140
Green	40A	*	14223
Yellowish Brown	3A	10 YR 5/6	30257
Green	42	5 G 6/8	24260
Red	82	2.5 R 4/10	11105
Green	42	5 G 6/8	24260
Orange	67	10 R 6/12	32246
Green	40	*	34108
Yellowish Brown	3A	10 YR 5/6	30257
Greenish Blue	25	7.5 B 5/7	25184

* No adequate color match available

TABLE II. DIFFERENTIAL FLICKERING DATA USING GREEN (40A) AND BROWN (2B) ART PAPERS AND WRATTEN FILTERS #26 (RED) AND #64 (GREEN)

Chop Freq. Cycles/sec.	Source Intensity Lumens (1) #26	Source Intensity Lumens (1) #64	Target Illumination Lumens/ft^2(2) #26	Target Illumination Lumens/ft^2(2) #64	Relative Reflectance, Lumens/ft^2 2B #26	Relative Reflectance 2B #64	Relative Reflectance 40A #26	Relative Reflectance 40A #64	Relative Contrast (3) 2B	Relative Contrast (3) 40A	(Col. 10) × (Col. 11)
1	2	3	4	5	6	7	8	9	10	11	12
6		No differential flickering produced									
8	37	17	0.121	0.055	6.92×10^{-4}	4.7×10^{-4}	4.53×10^{-4}	7.09×10^{-4}	32.5	32.1	1042
10	38	17	0.124	0.055	7.68×10^{-4}	4.78×10^{-4}	4.87×10^{-4}	7.26×10^{-4}	36.8	35.4	1302
12	53	17	0.173	0.055	11.4×10^{-4}	4.44×10^{-4}	7.0×10^{-4}	7.85×10^{-4}	50.6	55.0	2782
14	65	17	0.212	0.055	14.4×10^{-4}	4.44×10^{-4}	8.54×10^{-4}	7.09×10^{-4}	64.0	60.5	3870
16	51	17	0.166	0.055	10.1×10^{-4}	4.44×10^{-4}	5.72×10^{-4}	6.58×10^{-4}	44.8	37.6	1687
18	65	9.5	212	0.031	14.4×10^{-4}	2.31×10^{-4}	8.54×10^{-4}	4.1×10^{-4}	33.2	35.1	1165
20		Chopping frequency too high for good differential flickering									
23.5		Critical fusion frequency									

(1) Measured 1 foot from source

(2) Calculated for a distance of 17.5 ft. from source

(3) Product of reflectances of two filters on each art paper times 10^8; i.e., (Col. 6) × (Col. 7) or (Col. 8) × (Col. 9)

TABLE III. DIFFERENTIAL FLICKERING DATA USING GREEN (42) AND YELLOWISH BROWN (3A) ART PAPERS AND WRATTEN FILTERS #26 (RED) AND #64 (GREEN)

Chop Freq. Cycles/sec.	Source Intensity Lumens (1)		Target Illumination Lumens/ft² (2)		Relative Reflectance, Lumens/ft²				Relative Contrast (3)		
	#26	#64	#26	#64	3A #26	3A #64	42 #26	42 #64	3A	42	(Col. 10) × (Col. 11)
1	2	3	4	5	6	7	8	9	10	11	12
6	No differential flickering produced										
8	20	7	0.065	0.023	5.3×10^{-4}	2.74×10^{-4}	2.99×10^{-4}	4.95×10^{-4}	14.5	14.8	214
10	31	10	0.101	0.033	7.86×10^{-4}	3.68×10^{-4}	4.01×10^{-4}	6.48×10^{-4}	28.9	26.0	752
12	37	17	0.1[illegible]1	0.056	13.6×10^{-4}	6.58×10^{-4}	6.92×10^{-4}	11.5×10^{-4}	89.5	79.5	7110
14	47	14	0.154	0.046	13.0×10^{-4}	4.95×10^{-4}	6.67×10^{-4}	9.07×10^{-4}	64.4	60.5	3900
16	50	10	0.163	0.033	15.4×10^{-4}	4.44×10^{-4}	7.52×10^{-4}	6.92×10^{-4}	68.4	52.1	3560
18	57	9	0.186	0.029	16.8×10^{-4}	3.42×10^{-4}	8.36×10^{-4}	6.07×10^{-4}	57.4	50.8	2920
20	Chopping frequency too high for good differential flickering										
25.5	Critical fusion frequency										

(1) Measured 1 foot from source

(2) Calculated for a distance of 17.5 ft. from source

(3) Product of reflectances of two filters on each art paper, times 10^8; i.e., (Col. 6) × (Col. 7) or (Col. 8) × (Col. 9)

TABLE IV. DIFFERENTIAL FLICKERING DATA USING GREEN (42) AND RED (82) ART PAPERS AND WRATTEN FILTERS #26 (RED) AND #64 (GREEN)

Chop Freq. Cycles/sec.	Source Intensity Lumens (1)		Target Illumination Lumens/ft^2(2)		Relative Reflectance, Lumens/ft^2				Relative Contrast		
					82		42		(3)		(Col. 10) × (Col. 11)
	#26	#64	#26	#64	#26	#64	#26	#64	82	42	
1	2	3	4	5	6	7	8	9	10	11	12
6		No differential flickering produced									
8	26	11	0.085	0.036	8.97×10^{-4}	1.02×10^{-4}	3.25×10^{-4}	5.38×10^{-4}	9.15	17.5	160
10	40	12	0.131	0.039	15.1×10^{-4}	1.54×10^{-4}	5.46×10^{-4}	7.60×10^{-4}	23.3	41.5	968
12	68	17	0.222	0.056	28.4×10^{-4}	2.82×10^{-4}	10.4×10^{-4}	12.0×10^{-4}	80.2	125.0	10,000
14	60	16	0.196	0.052	23.7×10^{-4}	2.14×10^{-4}	8.28×10^{-4}	11.6×10^{-4}	50.7	96.0	4870
16	56	13	0.183	0.042	22.4×10^{-4}	1.71×10^{-4}	7.95×10^{-4}	8.38×10^{-4}	38.3	6.16	2550
18	51	8	0.166	0.026	18.3×10^{-4}	1.28×10^{-4}	7.70×10^{-4}	5.38×10^{-4}	23.4	41.5	970
20		Chopping frequency too high for good differential flickering									
26.5		Critical fusion frequency									

(1) Measured 1 foot from source

(2) Calculated for a distance of 17.5 ft. from source

(3) Product of reflectances of two filters on each art paper, times 10^8; i.e., (Col. 6) × (Col. 7) or (Col. 8) × (Col. 9)

TABLE V. DIFFERENTIAL FLICKERING DATA USING GREEN (40) AND ORANGE (67) ART PAPERS AND WRATTEN FILTERS #26 (RED) AND #64 (GREEN)

Chop Freq. Cycles/sec.	Source Intensity Lumens (1)		Target Illumination Lumens/ft^2(2)		Relative Reflectance, Lumens/ft^2				Relative Contrast		
					67		40		(3)		(Col. 10) × (Col. 11)
	#26	#64	#26	#64	#26	#64	#26	#64	67	40	
1	2	3	4	5	6	7	8	9	10	11	12
6		No differential flickering produced									
8	26	11	0.085	0.036	15.1×10^{-4}	2.56×10^{-4}	3.18×10^{-4}	3.84×10^{-4}	38.6	12.2	472
10	28	12	0.091	0.039	16.8×10^{-4}	2.73×10^{-4}	3.08×10^{-4}	3.93×10^{-4}	45.9	12.1	555
12	45	17	0.147	0.056	29.2×10^{-4}	4.44×10^{-4}	5.38×10^{-4}	6.50×10^{-4}	130.0	35.0	4550
14	46	17	0.150	0.056	29.2×10^{-4}	4.30×10^{-4}	4.87×10^{-4}	5.82×10^{-4}	126.0	28.3	3530
16	46	14	0.150	0.046	28.9×10^{-4}	3.92×10^{-4}	4.87×10^{-4}	5.13×10^{-4}	113.0	25.0	2820
18	56	10	0.183	0.033	36.1×10^{-4}	1.79×10^{-4}	5.63×10^{-4}	2.74×10^{-4}	64.6	15.4	995
20		Chopping frequency too high for good differential flickering									
27.5		Critical fusion frequency									

(1) Measured 1 foot from source

(2) Calculated for a distance of 17.5 ft. from source

(3) Product of reflectances of two filters on each art paper, times 10^8; i.e., (Col. 6) × (Col. 7) or (Col. 8) × (Col. 9)

TABLE VI. DIFFERENTIAL FLICKERING DATA USING YELLOWISH BROWN (3A) AND GREENISH BLUE (25) ART PAPERS AND WRATTEN FILTERS #26 (RED) AND #64 (GREEN)

Chop Freq. Cycles/sec.	Source Intensity Lumens (1)		Target Illumination Lumens/ft^2(2)		Relative Reflectance, Lumens/ft^2				Relative Contrast (3)		
					3A		25				(Col. 10) × (Col. 11)
	#26	#64	#26	#64	#26	#64	#26	#64	3A	25	
1	2	3	4	5	6	7	8	9	10	11	12
6		No differential flickering produced									
8		No differential flickering produced									
10	39	14	0.127	0.046	11.6×10^{-4}	5.98×10^{-4}	4.87×10^{-4}	6.23×10^{-4}	69.4	30.3	2100
12	47	17	0.153	0.056	14.2×10^{-4}	7.52×10^{-4}	6.15×10^{-4}	7.87×10^{-4}	107.0	48.4	5180
14	49	16	0.160	0.052	14.7×10^{-4}	6.75×10^{-4}	6.07×10^{-4}	6.75×10^{-4}	91.8	41.0	3770
16	48	12	0.157	0.039	13.0×10^{-4}	4.53×10^{-4}	5.38×10^{-4}	4.44×10^{-4}	59.0	23.9	1410
18	46	8	0.150	0.026	12.3×10^{-4}	2.99×10^{-4}	5.04×10^{-4}	2.99×10^{-4}	36.8	15.1	555
20		Chopping frequency too high for good differential flickering									
25		Critical fusion frequency									

(1) Measured 1 foot from source

(2) Calculated for a distance of 17.5 ft. from source

(3) Product of reflectances of two filters on each art paper, times 10^8; i.e., (Col. 6) × (Col. 7) or (Col. 8) × (Col. 9)

TABLE VII. DIFFERENTIAL FLICKERING DATA USING HOUSE PLANT AND ARMY FATIGUE JACKET AND WRATTEN FILTER COMBINATIONS

Desired Flicker	Most Favor-able Chop Rate, cyc/sec	Filter Combination	Source Intensity Lumens (1)		Target Illumination Lumens/ft^2 (2)		Light Ratio	Remarks
Plant	18	#26-#15	(#26) 500	(#15) 360	(#26) 1.63	(#15) 1.17	1.39	Apparent flicker in uniform could not be eliminated
Plant	16	#26-#55	(#26) 500	(#55) 320	(#26) 1.63	(#55) 1.04	1.56	Good differential flickering
Plant	14	#26-#55	(#26) 360	(#55) 230	(#26) 1.18	(#55) .751	1.57	Good differential flickering
Plant	14	#26-#64	(#26) 510	(#64) 400	(#26) 1.66	(#64) 1.30	1.27	Fair differential flickering but uniform flicker could not be eliminated; above 14 cps, both flicker
Uniform	16-18	#23A-#PC3	(#23A) 740	(#PC3) 480	(#23A) 2.42	(#PC3) 1.56	1.54	Fair differential flickering; >18 cps, <16 cps both flicker
Uniform	16-18	#29-#47	(#29) 420	(#47) 290	(#29) 1.37	(#47) 0.95	1.45	Fair differential flickering - as cps approaches 20 fusion occurs on plant but flicker on uniform is reduced
Uniform	18-22	#3-#64	(#3) 650	(#64) 420	(#3) 2.12	(#64) 1.37	1.55	Good differential flickering Best filter combination used for uniform flicker

TABLE VII (Concluded)

Desired Flicker	Most Favor-able Chop Rate, cyc/sec	Filter Combination	Source Intensity Lumens (1)		Target Illumination Lumens/ft^2 (2)		Light Ratio	Remarks
			(#23A)	(#47)	(#23A)	(#47)		
Uniform	18	#23A-#47	520	400	1.70	1.31	1.3	Good differential flickering
			(#23A)	(#47)	(#23A)	(#47)		
Uniform	20	#23A-#47	750	250	2.47	.817	3.0	Good differential flickering

(1) Measured one (1) foot from source

(2) Calculated for a distance of 17.5 ft. from source

TABLE VIII. REFLECTANCE VALUES (IN PERCENT) OF VARIOUS TERRAIN FEATURES AND BUILDING MATERIALS

Object	Wavelength in Microns						
I. Natural Terrain							
a. Soils:	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Dry yellow earth	8	16	37	55	69	76	82
Wet yellow earth	5	9	25	42	58	67	76
Dry sand	18	28	37	45	52	56	58
Wet sand	10	15	26	32	37	41	43
Dry red earth	8	8	20	28	33	35	37
Wet red earth	6	6	12	18	22	24	25
Dry brown earth	8	11	15	19	21	23	24
Wet brown earth	4	6	11	14	15	17	19
Dry loam	8	12	18	20	20	21	22
Wet loam	5	6	7	9	10	11	11
b. Vegetation:							
Grass	6	8	10	13	55	67	70
Evergreens	3	4	7	6	24	24	24
Straw	7	15	24	33	39	44	46
Dead grass	7	13	20	26	31	35	37
Dead brown lead	6	9	11	27	43	51	69
Dead yellow leaf	6	10	23	39	45	48	51
c. Terrain as seen from 4,000 feet:							
Green field		4	7	10			
Brown field		3	4	5			
Yellow-green vegetation		5	8	15			
Light sand		12	16	21			
Sandy ground		8	12	14			
Wet mud		5	8	9			
Mud covered with water		4	7	6			
Pond water		3	2	1			
Water with suspended material		3	4	4			
Dark volcanic rock		6	6	7			
Black asphalt runway		4	4	4			

TABLE VIII (Continued)

Object	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	Wavelength in Microns						
II. Building Materials:							
a. Paints:	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Black	4	4	4	4			
Earth brown	6	6	11	12			
Earth yellow	9	15	45	47			
Earth red	6	7	19	21			
Sand	15	24	42	43			
Desert sand	16	21	37	41			
Field drab	7	9	16	16			
Olive drab	4	7	11	9			
Forest green	4	6	7	5			
Dark green	5	7	6	6			
Sky gray	33	40	48	45			
Haze gray	35	33	24	24			
Blue gray	25	27	25	23			
Ocean gray	22	20	13	13			
Sea gray	14	13	12	10			
Slate gray	9	10	9	7			
Sea blue	7	6	5	4			
Red	5	5	25	75			
b. Materials:							
Concrete tiles (uncolored)		28	35	37	37	37	37
Concrete tiles (black)		9	9	9	9	9	9
Slates (silver gray)		19	20	21	21	21	21
Slates (blue gray)		12	13	14	14	15	16
Slates (dark gray)		10	12	12	12	11	10
Clay tiles (Dutch light red)		23	51	64	66	66	65
Clay tiles (red)		11	28	35	37	40	40
Clay tiles (red-brown)		13	25	30	33	40	41
Dark concrete	13	16	20	17			
Light concrete	25	32	37	38			
Galvanized iron	23	26	27	25			
Dirty galvanized iron		9	9	9	9	9	9
Aluminum	45	49	52	53			
Steel	29	31	34	35			

TABLE VIII (Concluded)

Object	Wavelength in Microns						
b. Materials: (Continued)	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Granite	10	15	20	22			
Asbestos cement		35	43	45	44	41	37
Weathered wood	9	11	8	10			
Weathered asphalt		9	10	11	11	11	11
Basalt	5	6	7	6			

TABLE IX. LUMINOUS REFLECTANCE OF VARIOUS NATURAL OBJECTS IN PERCENT

Class A. Water Surfaces	
1. Bay	3-4
2. Bay and river	6-10
3. Inland water	5-10
4. Ocean	3-7
5. Ocean, deep	3-5
Class B. Bare Areas and Soils	
1. Snow, fresh fallen	70-86
2. Snow, covered with ice	75
3. Limestone, clay	63
4. Calcareous rocks	30
5. Granite	12
6. Mountain tops, bare	24
7. Sand, dry	25
8. Sand, wet	18
9. Clay soil, dry	15
10. Clay soil, wet	7.5
11. Ground, bare, rich soil, dry	10-20
12. Ground, bare, rich soil, wet	5.5
13. Ground, black earth, sand loam	3
14. Field, plowed, dry	20-25
Class C. Vegetative Formations	
1. Coniferous forest, winter	3
2. Coniferous forest, summer	3-10
3. Deciduous forest, summer	10
4. Deciduous forest, fall	15
5. Dark hedges	1
6. Coniferous forest, summer, from airplane	3
7. Meadow, dry grass	3-6
8. Grass, lush	15-25
9. Meadow, low grass, from airplane	8
10. Field crops, ripe	10

TABLE IX (Concluded)

Class D. Roads and Buildings	
1. Earth roads	3
2. Black top roads	8
3. Concrete road, smooth, dry	35
4. Concrete road, smooth, wet	15
5. Concrete road, rough, dry	35
6. Concrete road, rough, wet	25
7. Buildings	9
8. Limestone tiles	25
Class E. Miscellaneous	
1. Black velvet	1
2. Newspaper	50
3. Aluminum	53-85
4. Aluminum paint	75
5. Gray paint	70
6. Olive drab paint	8
7. Russian vehicles	5-35
8. Nylon fabric, O.D.	10
9. Human skin, caucasian	45

TABLE X. DEFINITIONS AND CONVERSION FACTORS
(Definitions)

1.	Foveal (Central) Vision	- Vision using the small area at the center of the retina containing densely packed cones which function under brighter (photopic) light for fine discriminations and for perception of color differences.
2.	Parafoveal (Peripheral) Vision	- Vision using the area outside of the fovea primarily composed of rods which function under dim (scotopic) light for light-dark sensation. They do not respond to color difference nor are they sensitive to detail.
3.	Visual Acuity	- The ability of the eye to distinguish fine detail. It is measured by determining the smallest resolvable visual angle and is usually expressed as the reciprocal of that angle in minutes of arc; e.g., resolution of 0.5 minute of arc has an acuity value equal to 2.0.
4.	Visual Angle	- A measure of visual resolution expressed as the angle subtended at the eye by the object being viewed.
5.	Accommodation	- The change in shape of the lens of the eye in focusing from near to distant objects and the reverse.
6.	Convergence	- Action of the eye muscles in coordinating the lines of sight of each eye to fixate an object in space.

TABLE X (Continued)
(Definitions)

7. Threshold	- The minimum strength of a stimulus normally required to initiate a sensation. a. Absolute--value of a stimulus which is (on the average) just noticeable or just detectable. b. Relative--that difference between two stimuli which is (on the average) just noticeable.
8. Saturation	- The opposite of grayness or the amount of hue which is present in any given specimen, e.g., pink may be considered a red or low saturation because of its dilution with a white mixture.
9. Attention Value or Target Value	- That attribute of a stimulus which attracts an individual's attention.
10. Brightness Contrast	- Difference in the amount of light emitted or reflected from two surfaces.
11. Color Contrast	- Difference in the spectral composition, of light emitted or reflected from two surfaces.
12. Reflectance Factor	- The percentage or fraction of incident light that is reflected.
13. Direct or Specular Reflectance	- The incident light on a polished or glossy surface which reflects at an angle equal to the angle of incidence.
14. Diffuse Reflectance	- The reflection of incident light in all directions from a surface that is rough or composed of pigment particles.

TABLE X (Continued)
(Definitions)

15.	Compound Reflectance	- Reflection of incident light from surfaces having both spectral and diffuse reflectance qualities.
16.	I. C. I. *Color System	- A system of specifying color in terms of three primaries, Red (X), Green (Y) and Blue (Z), and their fractional amounts (x, y, z) which match a given sample under a specified illuminant.
17.	Munsell Color System	- A system of designating a surface color according to its hue, value and chroma.
18.	Meteorological Range	- The range at which the contrast transmission of the atmosphere is 2 percent. It is usually about 5/4ths of the visually determined range of large objects.
19.	Troland	- A retinal illumination unit. The retinal illumination in trolands is, E = (apparent pupil area in sq. mms.) × (luminance of source in candles per square meter) Twilight vision @ 10^{-4} ft lambert (3.3 candle ft^{-2}) is monochrome.

* The abbreviation I. C. I. (International Commission on Illumination) has been changed to C. I. E. which refers to the French name, Commission Internationale de L'Eclairage.

TABLE X. DEFINITIONS AND CONVERSION FACTORS (Continued)
(Conversion Factors)

Illumination Units

	Sea Mile Candle	Mile Candle	Meter Candle	Milliphot	Footcandle	Centimeter Candle
Sea Mile Candle	1.0	7.540×10^{-1}	2.911×10^{-7}	2.911×10^{-8}	2.705×10^{-8}	2.911×10^{-11}
Mile Candle	1.326	1.0	3.863×10^{-7}	3.863×10^{-8}	3.587×10^{-8}	3.863×10^{-11}
Meter Candle	3.435×10^{6}	2.589×10^{6}	1.0	1×10^{-1}	9.290×10^{-2}	1×10^{-4}
Milliphot	3.435×10^{7}	2.589×10^{7}	1×10	1.0	9.290×10^{-1}	1×10^{-3}
Footcandle	3.697×10^{7}	2.788×10^{7}	1.076×10	1.076	1.0	1.076×10^{-3}
Centimeter Candle	3.435×10^{10}	2.589×10^{10}	1×10^{4}	1×10^{3}	9.290×10^{2}	1.0

Value in unit shown at the top of the column equals the value in unit in the left column times conversion factor, i.e., 1 foot candle = 10.76 meter candles.

TABLE X. DEFINITIONS AND CONVERSION FACTORS (Concluded)
(Conversion Factors)

Brightness Units

	Lamberts	Footlamberts	Millilamberts	Microlamberts	Candles per square foot	Candles per square inch	Candles per square centimeter
L	1.0	9.290×10^{2}	1×10^{3}	1×10^{6}	2.957×10^{2}	2.054	3.183×10^{-1}
Ft-L	1.076×10^{-3}	1.0	1.076	1.076×10^{3}	3.183×10^{-1}	2.210×10^{-3}	3.426×10^{-4}
mL	1×10^{-3}	9.290×10^{-1}	1.0	1×10^{3}	2.957×10^{-1}	2.054×10^{-3}	3.183×10^{-4}
uL	1×10^{-6}	9.290×10^{-4}	1×10^{-3}	1.0	2.957×10^{-4}	2.054×10^{-6}	3.183×10^{-7}
C/ft^2	3.382×10^{-3}	3.142	3.382	3.382×10^{3}	1.0	6.944×10^{-3}	1.076×10^{-3}
C/in^2	4.869×10^{-1}	4.524×10^{-2}	4.869×10^{2}	4.869×10^{5}	1.440×10^{2}	1.0	1.550×10^{-1}
C/m^2	3.142×10^{-4}	2.919×10^{-1}	3.142×10^{-1}	3.142×10^{2}	9.290×10^{-2}	6.452×10^{-4}	1×10^{-4}
C/cm^2	3.142	2.919×10^{3}	3.142×10^{3}	3.142×10^{6}	9.290×10^{2}	6.452	1.0

Value in unit shown at the top of the column equals the value in unit in the left column times the conversion factor.

TABLE XI. PYROTECHNIC BINDER COMPOSITION CODE

1. Graphite
2. Linseed Oil
3. Castor Oil
4. Paraffin
5. Laminac 4116
6. PVC
7. Dextrin
8. Rosin
9. VAAR
10. Pluronic F-68
11. LP-2
12. Polyethylene
13. Tetranitracarbazole
14. Silicone Resin
15. Polyester Resin
16. Epoxide Resin
17. Dechlorane
18. Asphaltum
19. Parlon
20. Phenol Formaldehyde
21. Ethyl Cellulose
22. Polyvinylidene Chloride
23. Kel-F
24. Stafoam
25. PVA

TABLE XII. MISCELLANEOUS FUELS & OXIDIZERS CODE

1.	SbS_3	25.	C_2Cl_6
2.	Mg-Sr Alloy	26.	NH_4Cl
3.	Mg-Ba Alloy	27.	BHC
4.	Zr	28.	Shellac
5.	Hf	29.	Foreign Pitch
6.	C_6Cl_6	30.	Pine Root Pitch
7.	Ca Resinate	31.	Coal Pitch
8.	BaO_2	32.	$LiNO_3$
9.	Ammonium Perchlorate	33.	$Ca(NO_3)_2$
10.	Calcium	34.	Glycerine
11.	Boron	35.	$BaClO_3$
12.	Barium Chromate	36.	Stearic Acid
13.	CaB	37.	Ca Silicide
14.	MoO_3	38.	$SrCO_3$
15.	WO_3	39.	Mg-Al Alloy
16.	Nitrocellulose	40.	HgCl
17.	MnO_2	41.	Sr Oxalate
18.	CrO_2	42.	Wood Flour
19.	BiO_3	43.	$HgCl_2$
20.	SrO_2	44.	Charcoal
21.	Fe_2O_3	45.	Copper
22.	TFE Teflon	46.	TeO
23.	$Ca(NO_3)_2$	47.	$Sr(ClO_4)_2$
24.	$Cs(NO_3)_2$		

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TABLE XIV. RED FLARE CHARACTERISTICS

Index	CP-Sec/g	Candle Power	CP-Sec × 10⁻³	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref
1	52,000				530,000		24.0				28				1
2	52,000				530,000		24.0				28				1
3	43,000				640,000		34.0				21				1
4	43,000				640,000		34.0				21				1
5	41,000				400,000		23.3				29				1
6	41,000				362,000		21.5				30				1
7	40,000				382,000		22.0				28				1
8	39,000				206,000		12.1				37				1
9	38,000				214,000		13.4				32				1
10	37,000				360,000		22.0				32				1
11	36,000				292,000		18.3				26				1
12	35,000				147,000		10.0				41				1
13	34,000				420,000		27.0				31				1
14	33,500				125,000		8.4				39				1
15	33,000				250,000		20.4				27				1
16	33,000				250,000		20.4				27				1
17	32,500				545,000		38.0				27				1
18	32,500				545,000		38.0				23				1
19	32,000				188,000		12.5				25				1
20	32,000				428,000		29.0				27				1
21	32,000				120,000		8.0				42				1
22	30,000				185,000		13.3				31				1
23	28,000				74,500		5.7				47				1
24	27,500				286,000		24.0				31				1
25	27,259	92,000			57,285	40	5.3				45	Pinkish		1960	5
26	26,500				77,000		6.8				43				1
27	25,000				75,000		6.1				35				1
28	25,000				88,000		6.4				42				1
29	24,500				83,000		7.9				46				1
30	24,000				307,000		28.0				26				1
31	24,000				93,000		8.0				37				1
32	24,000				80,000		7.5				50				1
33	24,000				307,000		28.0				26				1
34	24,000	1,200,000	47,800		92,000		8.7			50		Whitish		1957	4
35	24,000	1,020,000	43,200		87,000		[illegible]			50		Yellowish		1957	4
36	23,556	9,500			49,502	40	5.4				50	Red		1960	5
37	23,000				58,000		5.8				48				1
38	23,000	85,000	5,700		63,000		6.1			90				1957	4
39	22,000				260,000		24.8				24				1
40	22,000				390,000		45.1				20				1
41	22,000				260,500		24.8				24				1
42	22,000	279,000	13,000		63,500		5.7			30				1957	4
43	21,500				71,500		8.0				35				1
44	21,111	75,000			46,700	37	5.4				46	Pinkish		1960	5
45	20,500				170,000		17.3				26				1
46	20,326	56,000			34,869	49	4.0				50	Red		1960	5
47	20,000				236,000		27.9				20				1
48	20,000				350,000		41.6				21				1
49	20,000				86,000		8.4				18				1
50	20,000				359,000		38.0				24				1
51	20,000				264,000		27.0				24				1
52	20,000				63,000		6.6				44				1
53	20,000				359,000		38.0				24				1
54	20,000				65,000		7.1				51				1
55	20,000				88,000		9.3				30				1
56	~20,000	35,000	280			8.0								1962	23
57	19,500				55,000		5.8				45				1

TABLE XIV. RED FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref.
58	19.000				45.500		4.9				53				1
59	19.000	104,000	3.300		41.300		4.9			90				1957	4
60	19.000	487.000	39,000		36.300		4.3			90				1957	4
61	19.000	487,000	39.200		36.000		4.3			90				1957	4
62	18.500				64.000		6.8				16				1
63	18.500				269.000		31.0				24				1
64	18.500				28[illegible].000		31.0				24				1
65	18.500				41.500		4.4				49				1
66	18.222	61.500			38.294	40	5.1				44	Pinkish		1960	5
67	18.200	63.000			39.228	39	5.1				45	Red		1960	5
68	18.000				54.000		7.1				49				1
69	18.000	224,000	13.000		37.700		4.7			90				1957	4
70	17.500				109.000		13.9				18				1
71	17.500				107.000		11.7				28				1
72	16.000				67.000		7.8				28				1
73	16.000				35.600		4.7				54				1
74	15.500				94.000		12.5				32				1
75	15.500				114.000		13.8				25				1
76	15.500				37.000		5.2				52				1
77	15.000				155.000		20.3				25				1
78	15.000				168.000		22.0				20				1
79	15.000				155.000		20.3				25				1
80	15.000				33.000		4.3				46				1
81	15.000				33.500		4.7				51				1
82	14.500				152.000		21.1				22				1
83	14.500				38.000		5.1				43				1
84	14.500				152.000		21.1				22				1
85	14.000				99.000		13.0				19				1
86	14.000				50.000		7.2				36				1
87	14.000				42.000		5.8				42				1
88	14.000				38.000		6.4				48				1
89	14.000				34.000		5.9				43				1
90	14.000	10.000	682		32.200		5.3			90				1957	4
91	13.500				54.000		7.4				21				1
92	13.500				31.000		4.6				51				1
93	13.000				108.000		16.0				25				1
94	13.000				108.000		16.0				25				1
95	13.000				41.500		6.2				37				1
96	13.000				36.000		5.4				42				1
97	13.000				43.000		6.1				21				1
98	12.500				50.500		7.7				18				1
99	12.500				78.500		13.3				16				1
100	12.500				78.500		11.1				18				1
101	12.500				34.000		4.8				19				1
102	12.500				32.[illegible]00		5.6				31				1
103	12.500				65.000		10.6				26				1
104	12.500				25.000		3.8				46				1
105	12.500				50.500		7.7				18				1
106	12.500				32.000		4.9				42				1
107	12.500				65.000		10.1				20				1
108	12.000				68.500		8.9				16				1
109	12.000				63.000		9.8				24				1
110	12.000				36.000		6.7				52				1
111	12.000				50.000		7.5				17				1
112	12.000				68.500		8.9				16				1
113	12.000				45.500		7.4				25				1
114	12.000				36.000		5.7				35				1

TABLE XIV. RED FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref
115	11.573	24,800			15,442	63	3.4				53	Red		1960	5
116	11.500				25,000		4.0				16				1
117	11.500				30,000		5.0				40				1
118	11.000				29,000		4.5				17				1
119	11.000				33,500		5.4				19				1
120	10.500				27,000		4.8				28				1
121	10.500				26,000		4.8				48				1
122	10.000				34,000		6.0				19				1
123	10.000				46,000		7.7				18				1
124	10.000				34,000		6.0				19				1
125	10.000				25,000		4.8				40				1
126	10.000				29,000		5.4				32				1
127	10.000				22,000		5.0				55				1
128	9.500				39,000		7.3				22				1
129	9.500				22,000		4.5				49				1
130	9.000				51,000		4.6				24				1
131	9.000				51,000		4.6				24				1
132	9.000				33,000		5.3				20				1
133	8.500				22,000		5.9				50				1
134	8.000				18,000		5.4				48				1
135	7.200				21,000		6.01				17				1
136	7.000				19,000		4.4				17				1
137	7.000				16,000		5.2				50				1
138	6.500				10,500		2.7				20				1
139	6.500				10,500		2.7				20				1
140	6.500				13,500		4.7				51				1
141	6.500				11,500		4.2				48				1
142	6.000				9,500		3.9				49				1
143	5.600				13,000		4.1				37				1
144	5.500				13,000		4.2				33				1
145	5.500				13,000		3.9				25				1
146	5.300				10,000		3.4				44				1
147	5.000				12,500		4.5				28				1
148	5.000				12,000		5.6				43				1
149	4.850				10,000		3.5				22				1
150	4.560				11,000		4.1				27				1
151	3.500				3,500		1.8				22				1
152	3.500				9,000		4.1				23				1
153	3.500				9,000		4.1				23				1
154	3.500				6,500		4.3				43				1
155	3.000				7,000		4.0				38				1
156	2.000				3,500		2.8				21				1
157	1.700				5,000		4.5				22				1
158	162	44,544	2,342			31.1							18,150	1962	20
159		700,000				45-60								1958	12
160		25,000				10±3								1958	12
161		25,000				10±3								1958	12
162		25,000				10±3								1958	12
163		25,000				10±3								1958	12
164		25,000				10±3								1958	12
165		25,000				10±3								1958	12
166		25,000				10±3								1958	12
167		25,000				10±3								1958	12
168		25,000				10±3								1958	12
169		25,000				10±3								1958	12
170		25,000				10±3								1958	12
171		25,000				10±3								1958	12

TABLE XIV. RED FLARE CHARACTERISTICS (Continued)

Index	CP-Sec g	Candle Power	CP-Sec × 10⁻³	CP-Sec/cc	CP in²	Sec Burning Time	in min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref
172		48,000				3-4.5								1958	12
173		48,000				3-4.5								1958	12
174		48,000				3-4.5								1958	12
175		48,000				3-4.5								1958	12
176		48,000				3-4.5								1958	12
177		48,000				3-4.5								1958	12
178		48,000				3-4.5								1958	12
179		48,000				3-4.5								1958	12
180		48,000				3-4.5								1958	12
181		48,000				3-4.5								1958	12
182		48,000				3-4.5								1958	12
183		48,000				3-4.5								1958	12
184		<<50,000				39.0								1961	18
185		29,000				38.6								1961	18
186		24,000				36.0								1961	18
187		34,000				31.8								1961	18
188		28,000				32.6								1961	18
189		28,000				38.0								1961	18
190														1966	13
191														1966	13
192														1966	13
193						180.0						Red		1963	19
194						120.0						Weak Red		1963	19
195						105.0						Strong Red		1963	19
196						80.0						Strong Red		1963	19
197														1958	12
198		35,000				4-10								1958	12
199		35,000				4-10								1958	12
200		4,200				4-8								1958	12
201		20				20-30								1958	12
202		5,000				50								1958	12
203		5,000				50								1958	12
204		10,000				30								1958	12
205		8,000				4-6								1958	12
206		850				1200								1958	12
207		850				900								1958	12
208		850				600								1958	12
209		850				300								1958	12
210														1959	6
211														1959	6
212														1959	6
213														1959	6
214														1959	6
215														1959	6
216														1959	6
217														1959	6
218														1959	6
219														1959	6
220														1959	6
221														1959	6
222														1959	6
223														1959	6
224														1959	6
225														1959	6
226														1959	6
227														1959	6
228														1959	6

TABLE XIV. RED FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec × 10⁻³	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref
229														1965	11
230														1952	21
231														1952	21
232		12,600				~66.9								1962	22
233					Erratic										1
234					Erratic										1
235		16,000			11,500		5.7				26	Pinkish			1
236		18,000			13,000		5.5				24				1
237		22,000			15,500		5.1				31				1
238		4,000			3,000		2.0				37	Orange			1
239		70,000			50,000		13.0				20	Whitish			1
240		35,500			25,000		5.4				25				1
241		22,000			15,500		3.4				39				1
242		3,500			2,500		2.3				40				1
243		190,000			135,000		25.0				19	Whitish			1
244		53,000			38,000		8.6				30				1
245		36,500			26,000		4.8				47				1
246		5,500			4,000		2.3				39				1
247		275,000			196,000		34.0				20	Whitish			1
248		93,500			67,000		9.1				30				1
249		46,500			33,000		4.4				36				1
250		2,000			1,400		2.3				33				1
251		370,000			264,000		44.0				25	Whitish			1
252		550,000			392,000		31.0				26	Pinkish			1
253		100,000			71,000		7.9				35				1
254		16,500			12,000		3.7				3[illegible]				1
255							Erratic								1
256		150,000			107,000		12.0				27	Pinkish			1
257		16,000			11,000		5.2				29				1
258		2,000			1,400		2.9				25	Yellowish			1
259							Erratic					Yellowish			1
260		14,500			10,500		7.1				30				1
261		23,500			17,000		5.5				32				1
262		11,000			8,000		3.3				41				1
263		46,000			33,000		6.9				21				1
264		38,000			27,000		5.5				24				1
265		17,500			12,500		4.0				38				1
266		67,000			48,000		4.7				25				1
267		53,000			38,000		6.4				31				1
268		25,500			18,000		4.6				37				1
269		119,000			85,000		11.7				26				1
270		78,500			56,000		6.7				32				1
271		17,500			12,500		4.5				36				1
272		16,400			117,000		10.6				33				1
273		58,000			41,000		6.7				35				1
274		11,000			8,000		4.1				30				1
275		36,000			26,000		7.2				28				1
276		6,500			4,500		4.3				30				1
277		1,000			700		2.6					Yellowish			1
278		13,000			9,000		4.6				31				1
279		[illegible]			12,000		4.6				35				1
280		15,000			10,500		4.1				50				1
281		56,000			40,000		7.7				23				1
282		44,000			31,000		6.3				33				1
283		30,000			21,000		6.5				47				1
284		25,500			18,000		5.5				55				1
285		86,000			61,000		10.5				26				1

TABLE XIV. RED FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref.
286		80,000			57,000		11.0				35				1
287		69,000			49,000		7.9				47				1
288		37,000			26,000		6.8				55				1
289		151,000			107,000		13.1				32				1
290		108,000			77,000		8.2				34				1
291		46,000			33,000		5.6				51				1
292		12,500			9,000		5.4				48				1
293		253,000			180,000		12.5				54				1
294		100,000			71,000		8.2				50				1
295		17,500			12,500		5.9				47				1
296		6,000			4,500		5.1				37				1
297		71,500			51,000		7.8				45				1
298		20,500			14,500		5.9				46				1
299		6,500			4,500		5.1				38				1
300		47,000			33,000		9.0				21				1
301		37,000			26,000		7.7				26				1
302		103,000			73,000		15.5				22				1
303		68,000			48,000		8.2				30				1
304		190,000			135,000		21.0				27				1
305		120,000			86,000		11.6				31				1
306		342,000			243,000		17.5				32				1
307		142,000			100,000		9.8				36				1
308		7,000			5,000		3.8				24				1
309		6,000			4,000		4.3				25				1
310		6,000			4,000		3.7				28				1
311															1
312		57,000			41,000		9.7				20				1
313		49,500			35,000		8.3				20				1
314		36,000			26,000		6.5				20				1
315		26,500			19,000		6.5				22				1
316		115,000			82,000		14.3				19				1
317		97,000			69,000		12.3				22				1
318		63,500			45,000		10.0				22				1
319		67,000			48,000		9.4				22				1
320		187,000			134,000		21.4				22				1
321		158,000			113,000		16.7				24				1
322		112,000			80,000		12.5				26				1
323		82,000			58,500		10.0				29				1
324		220,000			157,000		24.0				23				1
325		220,000			157,000		19.0				26				1
326		178,000			127,000		13.7				29				1
327		167,000			119,000		10.8				32				1
328		393,000			280,000		22.2				30				1
329		370,000			264,000		17.3				32				1
330		252,000			180,000		12.7				34				1
331		218,000			155,000		11.0				36				1
332		14,500			10,000		4.7				29				1
333		13,000			9,000		4.4				34				1
334		7,500			5,000		4.4				41				1
335		58,000			41,000		7.6				22				1
336		44,500			32,000		7.0				23				1
337		26,000			18,500		5.4				36				1
338		22,500			16,000		5.4				43				1
339		106,000			76,000		12.4				24				1
340		83,500			60,000		10.4				27				1
341		51,000			36,000		6.7				41				1
342		39,500			28,000		6.4				44				1

TABLE XIV. RED FLARE CHARACTERISTICS (Concluded)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	in/min Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Weight	Year Reported	Ref.
343		157,000			112,000		16.4				30				1
344		146,000			104,000		12.9				34				1
345		87,500			62,000		8.5				48				1
346		40,000			28,000		7.9				52				1
347		397,500			283,000		17.8				35				1
348		282,000			201,000		14.9				41				1
349		109,000			78,000		11.5				48				1
350		48,000			34,000		10.4				41				1
351		155,000			111,000		11.2				38				1
352		122,000			87,000		12.0				40				1
353		65,000			46,000		11.1				37				1
354					Erratic										1
355		110											90	1958	8
356															

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS

Index	CP-Sec/g	Candle Power	CP-Sec × 10^{3}	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec × 10^{3}*	Remarks	Year Reported	Ref.
1	165,052	112,000	1,568			14.0					4.5			1954	28
2	91,954	160,000	800			5.[illegible]					8.[illegible]			1954	28
3	85,227	250,000	750			4.0					8.8			1954	28
4	82,758	48,000	720			15.0					8.[illegible]			1954	28
5	81,700	1,000,000					.087 in sec							1967	40
6	78,222	64,000	704			11.0					4.8			1954	28
7	75,200	504,100					.087 in sec							1967	40
8	72,200	215,900					.087 in sec							1967	40
9	70,500	788,000					.087 in sec							1967	40
10	64,700	2,500,000					.087 in sec							1967	40
11	61,050	420,000	67,000			73					1,100			1965	30
12	58,900	697,000					13.2 sec in							1964	38
13	56,700	1,213,000					6.75 sec in							1964	38
14	56,025	373,500				48	.085 in sec								41
15	55,812	384,250					.087 in sec							1967	40
16	55,800	174,100					.087 in sec							1967	40
17	54,300	519,000					16.5 sec in							1964	38
18	53,600	1,020,000					7.39 sec in							1964	38
19	52,900	1,102,000					7.15 sec in							1964	38
20	51,500	507,500					4.73 sec in							1964	38
21	51,100	561,000					4.38 sec in							1964	38
22	50,600	282,000	7,400				5.34 in min							1958	45
23	50,000	613,800				70	.085 in sec								41
24	50,000	722,400				60	.10 in sec								41
25	50,000	1,084,000				40	.15 in sec								41
26	49,580	1,857,000	288,000			155					5,800			1965	30
27	49,200	1,017,000					7.18 sec in							1964	38
28	49,050	1,185,000					5.50 sec in							1964	38
29	48,900	1,341,000					4.80 sec in							1964	38
30	47,500	2,625,000					6.94 sec in							1964	38
31	46,000	415,000	91,000		70,000		3.4 in min			50				1957	4
32	45,900	580,000					3.82 sec in							1964	38
33	45,900	750,000					8.25 sec in							1964	38
34	45,300	2,485,000					6.57 sec in							1964	38
35	45,000	1,372,000				218	.085 in sec								41
36	45,000	1,674,000				180	.10 in sec								41
37	45,000	2,506,000				120	.15 in sec								41
38	44,8[illegible]	333,600					6.91 sec in							1964	38
39	44,8[illegible]	319,000	8,600				5.48 in min							1958	45
40	44,600	3[illegible]2,[illegible]	9,100				4.82 in min							1958	45
41	44,450	1,220,000					4.91 sec in							1964	38
42	44,430	158,000	8,400				3.03 in min							1958	45
43	44,350	765,000					8.86 sec in							1964	38
44	44,300	2,090,000					8.1 sec in							1964	38
45	44,300	1,160,000					15.4 sec in							1964	38
46	44,300	313,000	8,400				5.32 in min							1958	45
47	44,000	2,468,000					6.90 sec in							1964	38
48	44,000	159,000	8,200				2.71 in min							1958	45
49	43,800	170,000	9,200				2.77 in min							1958	45
50	43,800	293,000	8,700				4.77 in min							1958	45
51	43,500	454,000					6.5 sec in							1964	38
52	43,300	324,000	8,100				6.21 in min							1958	45
53	43,000	164,300	9,100				2.80 in min							1958	45
54	43,000	273,000	7,600				5.71 in min							1958	45
55	42,8[illegible]	178,000	8,900				2.54 in min							1958	45
56	42,8[illegible]	291,000	7,800				5.52 in min							1958	45
57	42,700	286,[illegible]	8,500				5.02 in min							1958	45
58	42,600	278,000	7,200				6.20 in min							1958	45
59	42,500	142,200		73,300 sec/cc	102,100									[illegible]	34
60	42,500	156,000	8,400				2.63 in min							1958	45
61	42,430	1,420,000	288,000			151					6,804			1965	30
62	42,300	1,673,000					.087 in sec							1967	40

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec × 10⁻³	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recog-nition	Grams Flare Weight	CP-Sec/# × 10⁻⁶	Remarks	Year Reported	Ref
63	42,300	153,000	8,400				2.78 in/min							1958	45
64	42,300	157,000	8,900				2.64 in/min							1958	45
65	42,200	1,330,000					12.7 sec/in							1964	36
66	42,100	161,000	8,000				3.25 in/min							1958	45
67	42,100	275,000	7,100				5.48 in/min							1958	45
68	42,000	345,000	29,000		58,100		3.3 in/min			50				1957	4
69	42,000	787,000	86,000		58,700		3.0 in/min			70				1957	4
70	42,000	787,000	86,400		59,000		3.0 in/min			70				1957	4
71	42,000	841,000					7.4 sec/in							1964	38
72	42,000	171,000	8,700				2.69 in/min							1958	45
73	42,000	150,000	7,900				2.76 in/min							1958	45
74	42,000	158,000	8,800				2.70 in/min							1958	45
75	41,800	262,000	7,600				5.90 in/min							1958	45
76	41,600	140,000	8,700				2.41 in/min							1958	45
77	41,500	311,000	8,300				5.64 in/min							1958	45
78	41,400	282,000	8,200				5.12 in/min							1958	45
79	41,300	147,000	7,800				2.88 in/min							1958	45
80	41,300	298,000	8,300				5.28 in/min							1958	45
81	41,200	164,000	8,700				2.78 in/min							1958	45
82	41,200	175,000	8,700				3.02 in/min							1958	45
83	41,200	316,000	7,900				6.08 in/min							1958	45
84	41,200	312,000	8,100				5.73 in/min							1958	45
85	41,200	287,000	8,600				4.85 in/min							1958	45
86	41,100	283,000	7,100				6.35 in/min							1958	45
87	41,000				785,000										1
88	41,000	287,000	8,000				5.27 in/min							1958	45
89	40,900	168,200					12.8 sec/in							1964	38
90	40,900	141,000	7,700				2.58 in/min							1958	45
91	40,800	140,000	7,700				2.57 in/min							1958	45
92	40,800	157,000	7,600				2.95 in/min							1958	45
93	40,800	165,000	8,600				2.83 in/min							1958	45
94	40,700	140,000	8,400				2.69 in/min							1958	45
95	40,700	170,000	8,500				2.90 in/min							1958	45
96	40,700	303,000	7,600				6.04 in/min							1958	45
97	40,700	281,000	8,100				5.95 in/min							1958	45
98	40,700	289,000	6,900				6.42 in/min							1958	45
99	40,700	292,000	7,000				6.33 in/min							1958	45
100	40,600	134,600		70,600 sec/cc	96,900									1966	34
101	40,500	336,500					6.39 sec/in							1964	38
102	40,500	158,000	8,500				2.72 in/min							1958	45
103	40,400	135,000	8,200				2.45 in/min							1958	45
104	40,300	305,000	7,600				6.13 in/min							1958	45
105	40,250	841,000					6.20 sec/in							1964	38
106	40,200	1,875,000					7.59 sec/in							1964	38
107	40,200	286,000	7,700				5.90 in/min							1958	45
108	40,200	285,000	7,100				6.57 in/min							1958	45
109	40,100	285,000	7,700				6.18 in/min							1958	45
110	40,000	4,425,600				259	.085 in/sec								41
111	40,000	5,191,000				220	.10 in/sec								41
112	40,000	7,808,000				147	.15 in/sec								41
113	40,000	277,000	6,900				6.26 in/min							1958	45
114	39,900	140,100		69,700 sec/cc	100,700									1966	34
115	39,800	290,500					7.36 sec/in							1964	38
116	39,800	141,000	8,300				2.52 in/min							1958	45
117	39,800	291,000	5,000				6.06 in/min							1958	45
118	39,700	1,928,000					7.41 sec/in							1964	38
119	39,700	169,000	8,300				2.96 in/min							1958	45
120	39,700	295,000	8,000				5.72 in/min							1958	45
121	39,700	287,000	7,500				5.55 in/min							1958	45
122	39,600	258,800					7.75 sec/in							1964	38
123	39,600	267,000	7,700				5.18 in/min							1958	45

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec × 10⁻³	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec × 10⁻³	Remarks	Year Reported	Ref
124	39,600	301,000	7,800				5.55 in/min							1958	45
125	39,500	127,200		69,100 sec/cc	91,500									1966	34
126	39,500	285,000	7,800				5.32 in/min							1958	45
127	39,500	278,000	6,900				6.33 in/min							1958	45
128	39,400	136,700		68,900 sec/cc	98,300									1966	34
129	39,400	140,000	8,300				2.53 in/min							1958	45
130	39,400	278,000	6,800				6.49 in/min							1958	45
131	39,400	293,000	7,600				5.57 in/min							1958	45
132	39,400	257,000	6,700				6.06 in/min							1958	45
133	39,300	128,000	8,100				2.46 in/min							1958	45
134	39,200	133,000	8,000				2.73 in/min							1958	45
135	39,200	132,000	7,700				2.72 in/min							1958	45
136	39,100	298,000	7,700				5.85 in/min							1958	45
137	38,900	122,000	7,900				2.36 in/min							1958	45
138	38,900	141,000	7,900				2.66 in/min							1958	45
139	38,900	288,000	7,800				5.93 in/min							1958	45
140	38,800	1,155,000					4.85 sec/in							1964	38
141	38,800	116,000	7,500				2.48 in/min							1958	4
142	38,800	147,000	8,100				2.47 in/min							1958	45
143	38,700	262,000	7,100				5.62 in/min							1958	45
144	38,600	412,100					5.3 sec/in							1964	38
145	38,600	301,000	7,800				5.70 in/min							1958	45
146	38,600	291,000	7,600				5.67 in/min							1958	45
147	38,500	134,000	7,900				2.54 in/min							1958	45
148	38,500	151,000	8,000				2.74 in/min							1958	45
149	38,400	126,000	7,800				2.53 in/min							1958	45
150	38,200	284,000	7,700				5.86 in/min							1958	45
151	38,100	123,000	7,400				2.61 in/min							1958	45
152	38,100	145,000	8,000				2.80 in/min							1958	45
153	38,100	152,000	7,200				3.07 in/min							1958	45
154	38,000	632,000	64,700		54,000					50				1957	4
155	38,000	136,000	8,000				2.56 in/min							1958	45
156	37,900	132,000	7,800				2.67 in/min							1958	45
157	37,900	270,000	7,300				5.47 in/min							1958	45
158	37,900	283,000	7,600				5.60 in/min							1958	45
159	37,900	276,000	7,400				5.77 in/min							1958	45
160	37,800	155,000	7,900				2.86 in/min							1958	45
161	37,800	290,000	7,500				5.92 in/min							1958	45
162	37,647	40,000	320			8.0					8.5			1959	28
163	37,600	106,000	7,300				2.29 in/min							1958	45
164	37,600	283,000	7,400				5.52 in/min							1958	45
165	37,400	474,000					3.82 sec/in							1964	38
166	37,400	130,000	7,600				2.62 in/min							1958	45
167	37,400	289,[illegible]	7,500				5.80 in/min							1958	45
168	37,300	133,000	7,000				2.74 in/min							1958	45
169	37,300	151,000	7,100				3.43 in/min							1958	45
170	37,200			1,164,000 sec/cc			8.57 sec/in							1963	37
171	37,200	229,000					9.24 sec/in							1964	38
172	37,200	286,000	7,400				5.63 in/min							1958	45
173	37,200	286,000	7,400				5.93 in/min							1958	45
174	37,100	122,700		63,900 sec/cc	88,000									1966	34
175	37,100	340,000					17.6 sec/in							1964	38
176	37,100	122,000	7,600				2.65 in/min							1958	45
177	37,100	131,000	7,100				3.00 in/min							1958	45
178	37,000	135,000	7,700				2.64 in/min							1958	45
179	36,900	289,000	7,500				5.57 in/min							1958	45
180	36,800	14[illegible],000	7,700				2.79 in/min							1958	45
181	36,600	1,818,000					8.10 sec/in							1964	38
182	36,600	406,000					14.3 sec/in							1964	38
183	36,600	286,000	7,400				5.86 in/min							1958	45

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec × 10^{-3}	CP-Sec/cc	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recog-Nition	Grams Flare Weight	CP-Sec/• × 10^{-6}	Remarks	Year Reported	Ref
184	36,500	153,000	7,600				2.91 in/min							1958	45
185	36,300	117,000	7,100				2.66 in/min							1958	45
186	36,300	149,000	6,900				3.25 in/min							1958	45
187	36,200	929,000					16.3 sec/in							1964	38
188	36,000				685,000		39.0 in/min								1
189	35,900	324,000					5.0 sec/in							1964	38
190	35,800	121,800		62,400 sec/cc	87,700									1966	34
191	35,400	119,000	7,300				2.46 in/min							1958	45
192	35,600	202,800					8.67 sec/in							1964	38
193	35,350	972,000					5.21 sec/in							1964	38
194	35,100	126,000					16.2 sec/in							1964	38
195	35,100	132,000	6,600				3.06 in/min							1958	45
196	35,000	133,000	6,100		52,800		3.3 in/min			50				1957	4
197	34,984	883,000	36,732			41.6					1,050			1965	32
198	34,900	276,000					5.56 sec/in							1964	38
199	34,800			1,083,000 sec/cc			8.75 sec/in							1963	37
200	34,800	416,850					4.17 sec/in							1964	38
201	34,800	271,000	6,700				6.30 in/min							1958	45
202	34,700			1,035,000 sec/cc			8.54 sec/in							1963	37
203	34,700	116,000	6,700				2.78 in/min							1958	45
204	34,500	109,000	6,600				2.99 in/min							1958	45
205	34,400			915,000 sec/cc			7.49 sec/in							1963	37
206	34,200	103,100	5,100	49,000 sec/cc	74,200	50.2					150			1966	2
207	34,200			980,000 sec/cc			8.52 sec/in							1963	37
208	34,100			965,000 sec/cc			7.99 sec/in							1963	37
209	34,100	118,000	6,600				2.86 in/min							1958	45
210	33,700	338,100					5.9 sec/in							1964	38
211	33,650	874,000					5.38 sec/in							1964	38
212	33,250	677,000					7.58 sec/in							1964	38
213	33,100	1,764,000					7.0 sec/in							1964	38
214	33,000	245,000	20,000		55,600		3.3 in/min			50				1957	4
215	33,000				445,000		32.0 in/min								1
216	32,700	982,000					13.5 sec/in							1964	38
217	32,600			1,002,000 sec/cc			8.76 sec/in							1963	37
218	32,450	66,000	389.4		44,126	59								1960	5
219	32,300	82,400	4,900	47,200 sec/cc	59,300	59.7					150			1966	2
220	32,200	109,200		56,200 sec/cc	78,600									1966	34
221	32,200			956,000 sec/cc			6.11 sec/in							1963	37
222	32,030	4,049,000	247,000			61					7,711			1965	30
223	31,900			916,000 sec/cc			4.52 sec/in							1963	37
224	31,600	219,800					7.88 sec/in							1964	38
225	31,400	123,200	4,700	45,200 sec/cc	88,400	38.4					150			1966	2
226	31,400			902,000 sec/cc			4.27 sec/in							1963	37
227	31,340	3,200	304								[illegible]			1959	28
228	31,000				386,000		26.7 in/min								1
229	30,600	178,000	917	43,600 sec/cc	575,000	5.2					30			1966	25
230	30,600			810,000 sec/cc			5.60 sec/in							1963	37
231	30,600			868,000 sec/cc			6.05 sec/in							1963	37
232	30,600			892,000 sec/cc			15.1 sec/in							1963	37
233	30,600	311,400					4.62 sec/in							1964	38
234	30,300			767,000 sec/cc			3.84 sec/in							1963	37
235	30,100			943,000 sec/cc			15.5 sec/in							1963	37
236	30,000				570,000		43.0 in/min								1
237	30,000				909,000 sec/cc		6.60 sec/in							1963	37
238	30,000				927,000 sec/cc		6.74 sec/in							1963	37
239	29,910	3,604,000	231,000			64					7,711			1965	37
240	29,800	173,300					10.5 sec/in							1964	38
241	29,400			796,000 sec/cc			4.12 sec/in							1963	37
242	28,900			890,000 sec/cc			4.71 sec/in							1963	37
243	28,900	2,256,000					4.57 sec/in							1964	38

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec • $\times 10^{-6}$	Remarks	Year Reported	Ref
244	28,800			878,000 sec/cc			6.53 sec/in							1963	37
245	28,400	83,100	4,300	41,300 sec/cc	59,800	51.3					150			1966	2
246	28,400			779,000 sec/cc			14.6 sec/in							1963	37
247	28,400			851,000 sec/cc			4.55 sec/in							1963	37
248	27,900	91,100	4,200	40,400 sec/cc	65,600	46.3					150			1966	2
249	27,900	80,900	4,200	40,400 sec/cc	58,200	50.5					150			1966	2
250	27,900			795,000 sec/cc			15.2 sec/in							1963	37
251	27,800	115,100	4,100	39,400 sec/cc	82,700	36.1	7.6 in/min				150			1966	2
252	27,700			840,000 sec/cc			4.74 sec/in							1963	37
253	27,200	1,938,000					4.75 sec/in							1964	38
254	27,000			808,000 sec/cc			6.22 sec/in							1963	37
255	26,800			8[illegible],000 sec/cc			14.6 sec/in							1963	37
256	26,800	2,260,000					4.03 sec/in							1964	38
257	26,200			818,000 sec/cc			15.3 sec/in							1963	37
258	25,700			790,000 sec/cc			15.4 sec/in							1963	37
259	25,700	117,200					13.4 sec/in							1964	38
260	25,650	1,596,000					5.19 sec/in							1964	38
261	25,500	2,041,000					4.45 sec/in							1964	38
262	25,408	9,600	249			26.0					9.9			1959	28
263	25,400	1,370,000					7.42 sec/in							1964	38
264	25,100	103,400	3,700	35,900 sec/cc	74,400	36.9	7.5 in/min				150			1966	[illegible]
265	25,000	535,000					6.6 sec/in							1964	38
266	24,500	102,800	4,000	38,500 sec/cc	74,000	38.4	7.1 in/min				150			1966	2
267	24,303	455,555	6,890			15.12					283.5			1962	20
268	24,280	1,846,000					4.79 sec/in							1964	38
269	24,100	189,500	3,600	39,500 sec/cc	136,300	19.2	12.5 in/min				150			1966	2
270	24,000	74,200	3,600	36,000 sec/cc	53,300	47.1	5.9 in/min				150			1966	2
271	24,000	94,000	3,600	36,000 sec/cc	67,600	38.3	7.1 in/min				150			1966	2
272	23,500	145,000	3,500	38,600 sec/cc	104,200	24.2	10.0 in/min				150			1966	2
273	23,079	274,120	6,543			23.90					283.5			1962	20
274	22,700	185,000	3,400	37,300 sec/cc	133,100	18.5	13.0 in/min				150			1966	2
275	22,500	187,900	3,400	37,100 sec/cc	135,100	18.0	13.5 in/min				150			1966	2
276	22,310	403,681	6,325			15.68					283.5			1962	20
277	22,300	190,800	3,600	39,500 sec/cc	137,300	18.4	13.1 in/min				150			1966	2
278	22,081	325,820	6,250			19.27					283.5			1962	20
279	21,925	210,969	6,216			29.45					283.5			1962	20
280	21,900	167,100	3,300	36,200 sec/cc	120,300	19.9	12.4 in/min				150			1966	2
281	21,600	987,000					7.6 sec/in							1964	38
282	21,250	1,834,000					4.00 sec/in							1964	38
283	20,800	173,200	3,100	34,000 sec/cc	121,700	18.4	13.1 in/min				150			1966	2
284	20,800	260,307	5,897			22.68					283.5			1962	20
285	20,000	144,900	2,900	31,800 sec/cc	104,300	19.2	12.5 in/min				150			1966	2
286	20,000				155,000		15.6 in/min								1
287	20,000				180,000		18.8 in/min								1
288	19,936	178,245	5,652			31.72					283.5			1962	20
289	19,802	423,978	5,614			13.24					283.5			1962	20
290	19,800	156,300	3,000	32,900 sec/cc	112,500	19.1	12.6 in/min				150			1966	2
291	19,400	140,000	582	29,400 sec/cc	450,000	4.2	56.2 in/min				30			1966	25
292	19,061	206,446	5,404			26.16					283.5			1962	20
293	18,878	254,212	5,352			21.10					283.5			1962	20
294	18,818	231,729	5,335			23.23					283.5			1962	20
295	18,700	87,300					12.9 in/min							1965	33
296	18,000	149,200	2,700	29,600 sec/cc	107,300	18.2	13.2 in/min				150			1966	2
297	17,700	173,660	5,018			28.88					283.5			1962	20
298	17,629	239,953	4,998			20.76					283.5			1962	20
299	17,600	147,700	2,600	28,500 sec/cc	106,100	17.9	13.2 in/min				150			1966	2
300	17,068	220,808	4,839			21.92					283.5			1962	20
301	17,000	42,000	4,300		31,100		3.9 in/min			50				1957	4
302	16,458	210,490	4,666			22.15					283.5			1962	20
303	16,000	40,200					6.0 in/min							1965	33

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec/# $\times 10^{-6}$	Remarks	Year Reported	Ref.
304	15,500				102,000		13.1 in/min								1
305	15,000				37,000		5.2 in/min								1
306	14,500				171,000		28.5 in/min								1
307	14,000				45,000		7.0 in/min								1
308	13,925	108,411	3,948			36.10					283.5			1962	20
309	13,813	244,367	3,916			16.04					283.5			1962	20
310	13,724	195,064	3,891			19.96					283.5			1962	20
311	13,700	101,500	547	20,000 sec/cc	328,000	5.4	6.4 in/min				40			1966	25
312	13,650	46,000			148,400	8.9	68.8 in/min				30			1964	44
313	13,506	138,110	3,829			27.71					283.5			1962	20
314	12,873	32,000	112			3.5					8.7			1959	28
315	12,723	104,193	3,607			34.62					283.5			1962	20
316	12,623	4,210	126.225			30		591.0	91		10		CP-Sec obtained	1967	39
317	12,600	17,400	506	24,300 sec/cc	56,000	29.0	8.5 in/min				40		from integrated	1966	25
318	12,500				240,000		46.0 in/min						curve, therefore		1
319	12,400				160,500		32.4 in/min						CP × Burning	1965	33
320	12,000	5,000	579		16,000		3.1 in/min			50			Time ≠ CP-Sec	1957	4
321	12,000	55,900	480	31,600 sec/cc	180,000	8.6	20.2 in/min				40			1966	25
322	12,000				54,000		10.3 in/min								1
323	11,600	26,400	467.3	20,400 sec/cc	78,600	19.3	13.9 in/min				40			1966	25
324	11,368	8,000	108			13.5					9.5			1959	28
325	11,200	9,700	446	21,200 sec/cc	31,400	46.3	5.4 in/min				40			1966	25
326	11,130	74,200			242,000	4.5	50.7 in/min				30			1964	44
327	10,779	79,041	3,056			38.64					283.5			1962	20
328	10,600	42,700	425	20,800 sec/cc	137,500	10.0	23.6 in/min				40			1966	25
329	10,529	74,442	2,985			40.06					283.5			1962	20
330	9,900	27,300	395.3	19,900 sec/cc	87,500	14.7	16.2 in/min				40			1966	25
331	9,700				38,500		7.7 in/min								1
332	9,636	110,627	2,732			24.48					283.5			1962	20
333	9,500				119,000		29.3 in/min								1
334	9,500				17,500		3.8 in/min								1
335	9,200	44,600	369	19,200 sec/cc	143,800	8.3	27.9 in/min				40			1966	25
336	9,100	44,400	364	17,500 sec/cc	146,000	8.2	30.2 in/min				40			1966	25
337	9,000				36,000		8.5 in/min								1
338	9,000				55,000		13.3 in/min								1
339	9,000				86,000		21.8 in/min								1
340	9,000				116,000		31.1 in/min								1
341	8,500	34,400	340.2	18,200 sec/cc	110,900	9.9	22.2 in/min				40			1966	25
342	8,500				167,000		47.0 in/min								1
343	8,400	12,600	336.3	17,100 sec/cc	41,800	26.2	8.8 in/min				40			1966	25
344	8,400	56,800	333	27,800 sec/cc	187,500	5.9	24.3 in/min				40			1966	25
345	8,300				27,500		6.9 in/min								1
346	8,000	14,400	72			5.0					9.0			1959	28
347	7,600	46,300	311	15,800 sec/cc	127,800	8.1	30.1 in/min				40			1966	25
348	7,400	17,000	224	10,300 sec/cc	54,900	13.3	19.1 in/min				30			1966	25
349	7,300	13,900	291	15,600 sec/cc	44,700	21.0	10.5 in/min				40			1966	25
350	7,200	10,600	286.6	12,700 sec/cc	34,400	27.1	10.6 in/min				40			1966	25
351	6,823	4,000	58			14.5					8.5			1959	28
352	6,818	4,000	60.0			15.0					8.8			1959	28
353	6,300				70,000		26.4 in/min								1
354	6,014	8,053	60.143			7.5		596.8	73		10.0			1967	39
355	6,006	8,580	60.061			8		588.8	79		10.0			1967	39
356	6,000	79,600	238.6	23,900 sec/cc	256,000	3.0	40.0 in/min				40			1966	25
357	5,468	1,600	43.2			27.0					7.9			1959	28
358	5,333	2,400	43.2			18.0					8.1			1959	28
359	5,066	2,400	45.6			19					9.0			1959	28
360	4,831	18,857	48.310			2.75		606.1	65		10.0			1967	39
361	4,413	1,600	38.4			24					8.7			1959	28
362	4,256	2,652	42.560			18		589.7	65		10.0			1967	39
363	4,141	1,600	35.2			22					8.5			1959	28
364	3,700	1,600	29.6			18.5					8.0			1959	28

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

[illegible]	CP-Sec/g	Candle Power	CP-Sec ×10^3	CP-Sec/[illegible]	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Reproduction	Grams Flare Weight	CP-Sec ×10^[illegible]	Remarks	Year Reported	Ref.
[illegible]	[illegible]	[illegible]	[illegible]			18.5					[illegible]			1954	[illegible]
[illegible]	[illegible]				4,500		2.4 in/min								[illegible]
[illegible]	[illegible]	[illegible]	34,354			[illegible]		587.[illegible]	72		[illegible]		CP-Sec obtained	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	33,792			14		587.[illegible]	68		[illegible]		from integrated	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			20					[illegible]		curve, therefore	1954	[illegible]
[illegible]	[illegible]	[illegible]	44,[illegible]		6,849	40							CP × Burning	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	32,250			18		588.[illegible]	67		[illegible]		Time × CP-Sec	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	32,[illegible]			15.5		590.2	73		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28,7[illegible]			16		592.0	71		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			43,800	4.1	38.7 in/min				4[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28,187			17		580.[illegible]	64		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	21,[illegible]			7		581.[illegible]	74		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	21,[illegible]			7		585.[illegible]	82		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]				2,500		2.2 in/min								
[illegible]	[illegible]	[illegible]	20,544			[illegible]		590.7	81		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	20,25[illegible]			13		579.[illegible]	84		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	14,4[illegible]			3.3		584.7	73		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			33,200	6.4	29.0 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			51.5					[illegible]			1953	[illegible]
[illegible]	[illegible]	[illegible]	14,4[illegible]			5		580.[illegible]	81		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	32.8			16.0					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	12.8			16.0					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	14,443			60		584.[illegible]	82		[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			13.5					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]				18,500	6.4	21.[illegible] in/min				4			[illegible]	[illegible]
[illegible]	[illegible]				400		2.5 in/min								
[illegible]	[illegible]	[illegible]			44,700	2.0	71.0 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			41,000	2.75	4.6 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			45,600	[illegible]	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			5,060	28.2	5.4 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			112					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			24,000	2.17	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			31,300	[illegible]	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]			[illegible]			184					[illegible]			[illegible]	[illegible]
[illegible]					1,100		4.7 in/min								
[illegible]	[illegible]	[illegible]			16,300	3.38	46.5 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			22,000	2.47	61.5 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			8,400	6.4	23.5 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			158					281			[illegible]	[illegible]
[illegible]	[illegible]		[illegible]			[illegible]					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			2,180	28.4	7.3 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			13,350	2.6	64.4 in/min				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			205					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			140					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]		[illegible]			[illegible]					[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			474	18.2	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]				[illegible]			[illegible]	[illegible]
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]							[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			558					[illegible]			[illegible]	[illegible]
[illegible]		[illegible]	[illegible]			214					[illegible]			[illegible]	[illegible]
[illegible]														[illegible]	[illegible]
[illegible]														[illegible]	[illegible]
[illegible]														[illegible]	[illegible]
[illegible]														[illegible]	[illegible]
[illegible]														1959	[illegible]
[illegible]														1959	[illegible]
[illegible]														[illegible]	[illegible]
[illegible]														1959	[illegible]
[illegible]														1959	[illegible]
[illegible]														[illegible]	[illegible]

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec x 10^3	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec x 10^?	Remarks	Year Reported	Ref
426														1959	6
427														1959	6
428														1959	6
429														1959	6
430														1959	6
431														1959	6
432														1959	6
433														1959	6
434														1959	6
435														1959	6
436														1959	6
437														1959	6
438														1959	6
439														1959	6
440														1959	6
441														1959	6
442														1959	6
443														1959	6
444		43,000				8								1962	24
445					88,500										
446					131,000										
447															
448															
449															
450														1960	26
451														1960	26
452														1960	26
453														1960	26
454														1960	26
455														1960	26
456		6,500	330		4,924	50.8	3.5 in/min							1960	26
457		9,800	504		7,424	51.4	3.5 in/min							1960	26
458		1,500	213		1,136	142.0	1.6 in/min							1960	26
459		2,100	289		1,590	137.6	1.6 in/min							1960	26
460		6,900	476		5,229	69.0	3.1 in/min							1960	26
461		5,300	502		4,015	94.7	2.3 in/min							1960	26
462		7,200	426		5,454	59.1	3.0 in/min							1960	26
463		7,800	438		5,909	56.2	3.9 in/min							1960	26
464		6,700	472		5,075	70.4	3.1 in/min							1960	26
465		7,300	404		5,530	55.5	3.9 in/min							1960	26
466		8,300	532		6,212	64.2	3.6 in/min							1960	26
467		6,400	398		4,848	61.7	3.6 in/min							1960	26
468								590	81					1964	27
469								588	68					1964	27
470								591	80					1964	27
471								587	71					1964	27
472								587	76					1964	27
473								587	73					1964	27
474								590	78					1964	27
475								591	78					1964	27
476		128,900	5,143			39.9								1962	22
477		96,300	4,796			49.8								1962	22
478		60,000	3,450			57.5								1962	22
479														1952	21
480														1952	21
481			126,200		182,000		7.7 in/min					23.6		1962	29
482			92,700		116,300		6.0 in/min					16.8		1962	29
483			60,400		549,000		3.0 in/min					17.9		1962	29
484			81,100		117,600		4.8 in/min					21.2		1962	29
485			81,500		165,400		6.8 in/min					23.2		1962	29

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Grams Flare Weight	CP-Sec/# $\times 10^{-6}$	Remarks	Year Reported	Ref.
486			81,700		106,300		4.1 in/min					23.4		1962	29
487			66,900		166,700		8.7 in/min					19.1		1962	29
488			84,700		178,700		5.9 in/min					24.5		1962	29
489			142,400		83,300		4.3 in/min					20.3		1962	29
490			225,400		130,500		4.6 in/min					30.[illegible]		1962	29
491			237,500		147,600		4.8 in/min					31.4		1962	29
492			186,500		167,000		6.3 in/min					28.7		1962	29
493			314,700		177,200		4.8 in/min					39.3		1962	29
494		165,000	5,700	6,500/cc	122,000	34.8	6.7 in/min					20.7		1962	29
495		116,000	6,200	8,100/cc	86,000	53.1	3.8 in/min					22.6		1962	29
496		36,000	3,300	4,300/cc	27,000	90.9	2.2 in/min					12.0		1962	29
497		212,000	7,100	8,500/cc	157,000	33.6	6.6 in/min					25.8		1962	29
498		132,000	6,500	7,800/cc	98,000	49.3	4.5 in/min					23.6		1962	29
499		39,000	3,300	4,200/cc	29,000	83.6	2.5 in/min					12.0		1962	29
500		214,000	7,600	8,700/cc	159,000	35.7	6.6 in/min					27.6		1962	29
501		68,000	4,300	5,200/cc	50,000	62.7	3.5 in/min					15.6		1962	29
502		22,000	1,800	2,200/cc	16,000	82.4	2.6 in/min					6.6		1962	29
503		190,000	5,500	6,300/cc	141,000	28.9	8.1 in/min					20.0		1962	29
504		213,000	7,100	8,300/cc	158,000	33.2	6.9 in/min					25.8		1962	29
505		155,000	5,800	7,000/cc	115,000	37.4	5.9 in/min					21.1		1962	29
506		214,000	6,300	7,200/cc	159,000	29.2	8.0 in/min					22.9		1962	29
507		223,000	7,100	8,100/cc	165,000	31.8	7.4 in/min					25.8		1962	29
508		93,000	4,400	5,000/cc	69,000	47.3	5.0 in/min					16.0		1962	29
509		232,000	6,600	7,300/cc	172,000	28.3	8.5 in/min					24.0		1962	29
510		196,000	6,600	7,500/cc	145,000	33.7	6.9 in/min					24.0		1962	29
511		56,000	2,600	3,000/cc	42,000	47.1	5.0 in/min					9.5		1962	29
512						-180								1965	31
513		1,788,000		-250,320/cc		-140								1965	35
514		3,720,000		-372,000/cc		-100								1965	35
515		3,955,000		-1,858,200/cc		-400								1965	35
516		75,000		-4,506/cc		60								1966	36
517		110,000		2,200/cc		20								1966	36
518		40,000		2,200/cc		55								1966	36
519		600,000	108,000			180								1966	36
520		1,000,000	180,000			180								1966	36
521		1,250,000	225,000			180								1966	36
522		1,000,000	180,000			180								1966	36
523		500,000	90,000			180								1966	36
524		2,000,000	300,000			150								1966	36
525		2,000,000	360,000			180								1966	36
526		120,000	3,000			25								1966	36
527		240,000	10,320			43								1966	36
528		275,000	16,500			60								1966	36
529		400,000	20,400			51								1966	36
530		275,000	15,125			55								1966	36
531		400,000	20,400			51								1966	36
532		600,000	30,000			50								1966	36
533		900,000	45,000			50								1966	36
534		600,000	30,000			50								1966	36
535		250,000	6,250			25								1966	36
536		80,000	4,800			60								1966	36
537		145,000	12,325			25								1966	36
538		55,000	1,375			25								1966	36
539		650,000	29,250-39,000			45-60								1958	12
540		350,000	57,750-68,250			165-195								1958	12
541		60,000	3,600-4,900			60-70								1958	12
542		800,000	156,000±12,000			195±15								1958	12
543		575,000-10^6				195±15								1958	12
544		1,500,000	540,000			360								1958	12
545		3,000,000	540,000			180								1958	12

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Continued)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recog-nition	Grams Flare Weight	CP-Sec/# $\times 10^{-6}$	Remarks	Year Reported	Ref.
546		500,000	90,000			180								1958	12
547		500,000	90,000			180								1958	12
548		70,000	25,000±2,100			360±30								1958	12
549		70,000	5,250			75								1958	12
550		70,000	6,300			90								1958	12
551		600,000-850,000				300-420								1958	12
552		40,000	2,200-2,800			55-70								1958	12
553		40,000	2,200			55								1958	12
554		20,000	200±60			10±3								1958	12
555		20,000	200±60			10±3								1958	12
556		12,000	120±36			10±3								1958	12
557		20,000	200±60			10±3								1958	12
558		20,000	200±60			10±3								1958	12
559		12,000	120±36			10±3								1958	12
560		20,000	200±60			10±3								1958	12
561		20,000	200±60			10±3								1958	12
562		20,000	200±60			10±3								1958	12
563		25,000	250±75			10±3								1958	12
564		25,000	250±75			10±3								1958	12
565		15,000	150±45			10±3								1958	12
566		36,000	108-162			3-4.5								1958	12
567		36,000	108-162			3-4.5								1958	12
568		36,000	108-162			3-4.5								1958	12
569		650	468			720								1958	12
570		650	468			720								1958	12
571		650	1,560-2,340			2400-3600								1958	12
572		18,000	72-180			4-10								1958	12
573		18,000	72-180			4-10								1958	12
574		2,000	8-20			4-10								1958	12
575		9,000	36-72			4-8								1958	12
576		20	.4-.6			20-30								1958	12
577		4	.08-.12			20-30								1958	12
578		50,000				36								1958	12
579		50,000				36								1958	12
580		3,000				18-20								1958	12
581		50,000				30								1958	12
582		77,607	2,435			31.96					283.5			1962	20
583		376,859	6,283			16.68					283.5			1962	20
584		239,390	5,330			22.35					283.5			1962	20
585		236,900	5,549			23.50					283.5			1962	20
586		91,699	4,541			49.40					283.5			1962	20
587		256,400	4,627			18.08					283.5			1962	20
588		227,900	5,514			24.20					283.5			1962	20
589		222,700	5,474			24.64					283.5			1962	20
590		35,700				8								1965	11
591														1962	42
592		1,900,000				180								1966	43
593		1,100,000				209								1966	43
594		910,000				213								1966	43
595		1,670,000				148								1966	43
596		1,710,000				147								1966	43
597		1,600,000				197								1966	43
598		1,600,000				196								1966	43
599		1,600,000				199								1966	43
600		2,000,000				138								1966	43
601		2,000,000				134								1966	43
602		2,000,000				139								1966	43
603		1,500,000				142								1966	43
604		1,870,000				142								1966	43
605		1,890,000				138								1966	43

TABLE XV. YELLOW AND WHITE FLARE CHARACTERISTICS (Concluded)

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recog-nition	Grams Flare Weight	CP-Sec/# $\times 10^{-6}$	Remarks	Year Reported	Ref.
606		1,140,000				174								1966	43
607		1,260,000				173								1966	43
608		1,270,000				157								1966	43
609											30			1964	44
610											35			1964	44

TABLE XVI. GREEN FLARE CHARACTERISTICS

Index	CP-sec/g	Candle-Power	CP-sec $\times 10^{-3}$	CP-sec/cc CP-sec/in²	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Wgt.	Year Reported	Ref.
1	17,500				348,000		38.1 in/min								1
2	17,500				360,000		40.3 in/min								1
3	14,000				45,000		5.1 in/min								1
4	13,000				53,000		6.7 in/min								1
5	13,000				186,000		26.8 in/min								1
6	9,800				59,500		10.7 in/min								1
7	9,600	16,300	1,200	16,800	11,800	63.7	2.8 in/min				.337			1966	2
8	8,100	21,400	1,200	16,800	15,500	53.9	3.4 in/min				.353			1966	2
9	7,700	14,600	385,000			25.6				50	.40		50	1956	3
10	7,200	17,000	1,100	15,400 cp/cc	12,200	64.4	2.9 in/min				.299			1966	2
11	7,100	18,500	1,100	15,400	13,300	57.1	3.3 in/min				.353			1966	2
12	7,000	198,000	15,000		14,600		4.7 in/min			50				1957	4
13	7,000	198,000	14,900		15,000		4.7 in/min			50				1957	4
14	6,900	17,400	1,000	12,700	12,400	63.0	3.2 in/min				.385			1966	2
15	6,700	18,500	1,010	14,100	13,100	55.5	3.4 in/min				.354			1966	2
16	6,700	13,800	335			24.2				70	.44		50	1956	3
17	6,660	12,000	333,000			27.7				70	.41		50	1956	3
18	6,400	18,900	960	13,500	13,600	53.6	3.5 in/min				.392			1966	2
19	6,320	12,900	316			24.5				70	.44		50	1956	3
20	6,300	15,300	950	13,300	11,700	61.2	3.0 in/min				.333		50	1966	2
21	6,281	16,000		9,963/in²		53	3.7 in/min				.41			1960	5
22	6,260	9,500	313,000			32.9				70	.43		50	1956	3
23	6,240	10,400	312,000			30.0				70	.42		50	1956	3
24	6,220	11,200	311			27.3				70	.35		50	1956	3
25	6,200	15,500	960	12,200 cp-sec/cc	11,100	62.0	3.3 in/min				.355			1966	2
26	6,200	15,200	940	13,200	10,900	62.2	3.0 in/min				.364			1966	2
27	6,200	10,300	310,000			30.0				50	.43		50	1956	3
28	6,200	15,500		9,651/in²		54	3.6 in/min				.41			1960	5
29	6,100	14,400	900	11,500	10,300	52.9	3.4 in/min				.368			1966	2
30	6,060	11,800	303			25.6				70	.44		50	1956	3
31	6,060	8,500	303,000			35.7				50	.44		50	1956	3
32	6,000	68,000	4,000		11,400		4.8 in/min			70				1957	4
33	5,980	9,300	299			32.1				70	.36		50	1956	3
34	5,900	9,000	295			30.8				70			50	1956	3
35	5,900	14,000	890	11,300	10,100	63.2	3.3 in/min				.399			1966	2
36	5,880	10,300	294,000			28.6				70	.45		50	1956	3
37	5,880	10,200	294			28.9				70			50	1956	3
38	5,800	14,400	870	11,100	10,400	60.4	3.4 in/min				.394			1966	2
39	5,760	11,600	288			24.8				70	.44		50	1956	3
40	5,741	12,500		7,783/in²		62	3.1 in/min				.41			1960	5
41	5,700	13,800	850	11,900	9,900	62.6	3.0 in/min				.332			1966	2
42	5,620	9,500	281			29.6				70			50	1956	3
43	5,600	15,200	830	11,700	11,000	55.6	3.3 in/min				.341			1966	2
44	5,540	11,000	277			25.2				70	.44		50	1956	3
45	5,520	11,500	276			24.1				50	.41		50	1956	3
46	5,500	7,100	274,000			38.6				50	.36		50	1956	3
47	5,400	7,800	270,000			34.6				90	.44		50	1956	3
48	5,360	10,500	268			25.6				50	.41		50	1956	3
49	5,300	13,000	790	11,000	9,500	59.6	3.2 in/min				.403			1966	2
50	5,300	9,400	265			28.3				70	.36		50	1956	3
51	5,280	3,800	264,000			69.5				70	.42		50	1956	3
52	5,260	8,700	263			30.2				70	.42		50	1956	3
53	5,260	9,100	263			28.9				70	.44		50	1956	3
54	5,200	6,400	260,000			40.7				90	.47		50	1956	3
55	5,100	13,200	770	9,800	9,500	57.7	3.5 in/min				.452			1966	2
56	5,100	7,000	255,000			36.5				90	.44			1956	3

TABLE XVI. GREEN FLARE CHARACTERISTICS (Continued)

Index	CP-sec/g	Candle-Power	CP-sec $\times 10^{-3}$	CP-sec/cc CP-sec/in^2	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Wgt.	Year Reported	Ref.
57	5,080	6,400	254			39.9				90	.38		50	1956	3
58	5,060	9,100	253			27.9				50	.41		50	1956	3
59	5,000	12,000	740	9,400	8,600	62.0	3.3 in/min				.364			1966	2
60	5,000	6,400	250			29.1				90	.47		50	1956	3
61	6,000	7,600	250			33.0				70	.43		50	1956	3
62	5,000	4,000	250		13,000		5.1 in/min			90				1957	4
63	5,000	17,000	1,400		12,600		5.2 in/min			90				1957	4
64	5,000	30,000	970		11,900		4.8 in/min			90				1957	4
65	5,000	59,000	3,200		13,400		4.9 in/min			70				1957	4
66	4,960	5,600	248			44.1				90	.41		50	1956	3
67	4,940	5,200	247			47.5				90	.41		50	1956	3
68	4,900	7,300	245			33.6				90	.37		50	1956	3
69	4,900	11,500	730	9,300	8,100	63.4	3.2 in/min				.374			1966	2
70	4,822	10,500		6,538/in^2		62	3.2 in/min				.42			1960	5
71	4,800	4,900	240			49.0				90	.49		50	1956	3
72	4,600	11,100	700	8,900	8,000	62.9	3.3 in/min				.373			1966	2
73	4,600	11,000	690	8,800	7,900	62.3	3.3 in/min				.439			1966	2
74	4,600	11,600	720	9,200	8,400	61.6	3.3 in/min				.376			1966	2
75	4,560	4,800	228			47.5				70	.39		50	1956	3
76	4,560	5,300	228			43.0				90	.41		50	1956	3
77	4,560	6,100	228			37.4				90	.38		50	1956	3
78	4,520	4,600	226			49.1				90	.44		50	1956	3
79	4,520	5,600	226			40.3				70	.36		50	1956	3
80	4,460	4,900	223			45.8				90	.48		50	1956	3
81	4,340	3,800	217			56.6				90	.44		50	1956	3
82	4,140	4,900	207			42.3				90	.45		50	1956	3
83	4,120	2,400	206			84.5				70	.43		50	1956	3
84	4,100	4,000	205			51.2				90	.35		50	1956	3
85	4,020	5,300	201			38.4				70	.42		50	1956	3
86	3,940	3,900	197			50.6				50	.41		50	1956	3
87	3,820	3,500	192			55.3				90	.39		50	1956	3
88	3,660	3,100	183			59.0				90	.39		50	1956	3
89	3,600	2,800	180			64.3				70	.43		50	1956	3
90	3,600	2,800	180			64.3				90	.49		50	1956	3
91	3,300				6,500		2.9 in/min								1
92	3,300	3,100	165			52.8				90	.40		50	1956	3
93	3,260	2,500	163			65.2				90	.41		50	1956	3
94	3,100	2,500	155			62.0				50	.39		50	1956	3
95	3,000	86,000	6,200		7,000		4.8 in/min			50		Whitish		1957	4
96	2,900	2,400	145			60.5				90	.41		50	1956	3
97	2,000	46,000	3,300		4,000		4.8 in/min			50		Whitish		1957	4
98						9.3					Good		8.8	1965	11
99						10.2					Good		9.8	1965	11
100						17.5					Poor		9.8	1965	11
101						12					Fair		9.8	1965	11
102						14.9					Poor		8.9	1965	11
103						7.5					Very Good		9.8	1965	11
104						49.3					Poor		9.8	1965	11
105						105					Yellowish		9.8	1965	11
106						12.8					Poor		9.8	1965	11
107						40.8					Yellowish		9.8	1965	11
108						11					Very Good		9.8	1965	11
109						72.6					Yellowish		9.8	1965	11
110						44.4					Yellowish		9.8	1965	11
111						35.8					Yellowish		9.8	1965	11
112						17.2					Yellowish		9.8	1965	11

TABLE XVI. GREEN FLARE CHARACTERISTICS (Continued)

Index	CP-sec/g	Candle-Power	CP-sec $\times 10^{-3}$	CP-sec/cc CP-sec/in^2	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Wgt.	Year Reported	Ref.
113						12.2					Good		9.8	1965	11
114						21.8					Good		10.1	1965	11
115						18.2					Good		9.8	1965	11
116						8.8					Very Good		9.8	1965	11
117						13.0					Very Good		9.8	1965	11
118						~14.7					Very Good		9.8	1965	11
119						12.2					Very Good		9.8	1965	11
120						12.2					Very Good		9.8	1965	11
121						18.2					Yellowish		9.8	1965	11
122						9.5					Very Good		9.8	1965	11
123						10.5					Good		9.8	1965	11
124						16.5					Good		9.8	1965	11
125						22					Yellowish		9.8	1965	11
126						11					Whitish		9.8	1965	11
127						~15					Poor to Fair		9.8	1965	11
128						75					Yellowish		9.3	1965	11
129						46					Yellowish		9.8	1965	11
130						24.2					Fair		9.8	1965	11
131						12					Poor		9.8	1965	11
132						48					Yellowish		10.6	1965	11
133						Dud							10.6	1965	11
134						13.8					Very Good		9.6	1965	11
135						22					Yellowish		9.8	1965	11
136						30.5					Yellowish		9.8	1965	11
137						9.2					Very Good		9.8	1965	11
138						18.8					Whitish		9.8	1965	11
139						16.0					Whitish		9.8	1965	11
140						~19.9					Good		9.8	1965	11
141						15.2					Good		9.8	1965	11
142						Dud							15.0	1965	11
143						20.5					Good		9.8	1965	11
144						11					Very Good		9.8	1965	11
145						10.2					Very Good		9.8	1965	11
146						62					Black Smoke-P		9.8	1965	11
147						13.4					Yellowish		9.8	1965	11
148						~41					Yellowish		9.8	1965	11
149						46.6					Yellowish		15.6	1965	11
150						8.2					Very Good		9.8	1965	11
151						27					Fair		9.95	1965	11
152						27.8					Yellowish		9.95	1965	11
153						10.0					Very Good		9.5	1965	11
154						27.2					Yellowish		9.95	1965	11
155						18					Very Good		9.5	1965	11
156						18.8					Yellowish		9.5	1965	11
157						35.6					Yellowish		9.95	1965	11
158						Dud							10.0	1965	11
159						Dud							10.0	1965	11
160						Dud							8.0	1965	11
161						27					Fair		9.8	1965	11
162						~18.5					Very Good		9.95	1965	11
163						~24.5					V.G.-Fair		9.5	1965	11
164						14.2					Very Good		10.0	1965	11
165						20.0					Fair		9.5	1965	11
166						70.0					Yellowish		9.5	1965	11
167						15.5					Very Good		9.3	1965	11

TABLE XVI. GREEN FLARE CHARACTERISTICS (Continued)

Index	CP-sec/g	Candle-Power	CP-sec ×10^{-3}	CP-sec/cc CP-sec/in²	CP/in²	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Wgt.	Year Reported	Ref.
168						17.8					Very Good		10.0	1965	11
169						40.0					Good		9.5	1965	11
170						29.4					Good-V.G.		10.0	1965	11
171		18,400						576	50					1964	14
172		7,000						579	60					1964	14
173		12,420						581	55					1964	14
174		6,960						576	63					1964	14
175		28,960						578	59					1964	14
176		11,770						569	64					1964	14
177		90,000				45-60								1958	12
178		90,000				360±30								1958	12
179		20,000				10±3								1958	12
180		20,000				10±3								1958	12
181		20,000				10±3								1958	12
182		20,000				10±3								1958	12
183		20,000				10±3								1958	12
184		20,000				10±3								1958	12
185		20,000				10±3								1958	12
186		20,000				10±3								1958	12
187		20,000				10±3								1958	12
188		25,000				10±3								1958	12
189		25,000				10±3								1958	12
190		30,000				10±3								1958	12
191		T25,000				T-2.5-4								1958	12
		S20,000				S-3-4.5								1958	12
192		T25,000				T-2.5-4								1958	12
		S20,000				S-3-4.5									
193		T25,000				T-2.5-4								1958	12
		S20,000				S-3-4.5									
194		T25,000				T-2.5-4								1958	12
195		T25,000				T-2.5-4								1958	12
196		T25,000				T-2.5-4								1958	12
197		S20,000				S-3-4.5								1958	12
198		S20,000				S-3-4.5								1958	12
199		S20,000				S-3-4.5								1958	12
200		S28,000				S-3-4.5								1958	12
201		S28,000				S-3-4.5								1958	12
202		S28,000				S-3-4.5								1958	12
203		7,000				4-10								1958	12
204		9,000				4-8								1958	12
205		20				20-30								1958	12
206		600				6								1958	12
207														1959	6
208														1959	6
209														1959	6
210														1959	6
211														1959	6
212														1959	6
213														1959	6
214														1959	6
215														1959	6
216														1959	6
217														1959	6
218														1959	6
219		16,000	800			50s								1962	7
220														1962	7

TABLE XVI. GREEN FLARE CHARACTERISTICS (Concluded)

index	CP-sec/g	Candle-Power	CP-sec × 10^{-3}	CP-sec/cc CP-sec/in^2	CP/in^2	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Color Recognition	Color Value	Observed Color	Grams Flare Wgt	Year Reported	Ref
221		65												1958	8
222														1960	9
223														1960	9
224						~83.4	2.4 in/sec							1960	9
225						45-80								1960	15
226						63								1961	10
227						Erratic									1
228		3,800								90	45		50	1965	11
229		25,800				8.5								1965	11
230						5.8					Good		9.8	1965	11
231						~10.9					Very Good		9.8	1965	11
232						15					Poor		9.8	1965	11
233						16					Good		9.8	1965	11
234						15					Good		9.8	1965	11
235						8.3					Very Good		9.8	1965	11
236						9.2					Very Good		9.8	1965	11
237							67 g/sec	563						1966	13
238							1.1 g/sec	575						1966	13
239							45 g/sec	~567						1966	13
240							5 g/sec	~540						1966	13
241														1959	6
242														1959	6

TABLE XVII. BLUE FLARE CHARACTERISTICS

Index	CP-Sec/g	Candle Power	CP-Sec $\times 10^{-3}$	CP-Sec/cc	Sec Burning Time	Burning Rate	Dominant λ (mμ)	Color Purity (%)	Year Reported	Ref.
1	~ 188	~ 727	~ 47		64.6	20 s/in	567	76	1962	17
2		250							1963	16
3		851			67	16-20 s/in			1963	16
4		583							1963	16
5									1962	17
6									1959	6
7									1959	6

TABLE XVIII. COMPOSITION CODE, RED FLARES

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
1			80		20			
2			80		20			
3			75		25			
4			75		25			
5		Grade A Mg Atomized	75					33
6		Grade A Mg Atomized	80					33
7		Grade A Mg Atomized	70					33
8			66.6		28.6		6	
9			79.0		19.8		6	
10		Grade C Mg (Ground)	80		20			
11			69.4		29.7		6	
12			71.4		23.8		6	
13		Grade C Mg (Ground)	75		25			
14			66.6		28.6		6	
15		Grade A Mg Atomized	80		20			
16			80		20			
17			70		30			
18			70		30			
19		Grade A Mg Atomized	60					33
20		Grade C Mg (Ground)	70		30			
21			54.5		36.4		6	
22			57.1		38.2		6	
23			52.2		34.8		6	
24		Grade A Mg Atomized	75		25			
25	FR-502		51.1		34.1		6.5	
26			76.0		19.0		6	
27			45.5		45.5		6	
28			54.5		36.4		6	
29			76		19		6	
30		Grade A Mg Atomized	70		30			
31			45.5		45.5		6	
32			63.6		27.3		6	
33			70		30			
34		4.18 inch diameter - Steel Case	51.0		34.0		6.5	
35		3.88 inch diameter - Steel-Paper Liner	51.0		34.0		6.5	
36	FR-503		46.8		38.3		6.5	
37			63.6		27.3		6	
38		1.31 inch diameter	51.0		34.0		6.5	
39		Grade A Mg Atomized	60		40			
40		Grade A Mg Atomized	80					32
41			60		40			
42		2.38 inch diameter	51.0		34.0		6.5	

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
43			84.2		14.8		6	
44	FR-505		44.5		39.0		6.5	
45			59.5		39.6		6	
46	FR-504		46.8		38.3		6.5	
47		Grade A Mg Atomized	60					32
48		Grade A Mg Atomized	70					32
49		Grade A Mg Atomized	48					33
50			60		40			
51		Grade C Mg (Ground)	60		40			
52			43.5		43.5		6	
53			60		40			
54			52.2		34.8		6	
55			57.1		38.2		6	
56	T133E2	Ground Illumination Signal	30.0		47.0		6.5	
57			43.5		43.5		6	
58			41.6		41.6		6	
59		1.80 inch diameter	51.0		34.0		6.5	
60		4.13 inch diameter	51.0		34.0		6.5	
61		4.13 inch diameter Paper Case	51.0		34.0		6.5	
62		Grade A Mg Atomized	43					33
63			50		50			
64			50		50			
65			33.4		50.0		6	
66	FR-506		40		43.5		6.5	
67	FR-507		40		43.5		6.5	
68			68.2		22.7		6	
69		2.75 inch diameter	51.0		34.0		6.5	
70		Grade A Mg Atomized	47					32
71		Grade C Mg (Atomized)	60		40			
72			47.6		47.6		6	
73			50.0		33.4		6	
74			47.6		47.6		6	
75			49.5		49.5		6	
76			40.0		40.0		6	
77			40		60			
78		Grade C Mg (Ground)	50		50			
79			40		60			
80			30.4		53.0		6	
81			32.0		48.0		6	
82		Grade A Mg Atomized	50		50			
83			34.8		52.2		6	
84			50		50			

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
85		Grade C Mg (Ground)	40		60			
86			36.4		54.5		6	
87			34.8		52.2		6	
88			72.7		18.2		6	
89			81.0		14.3		6	
90		0.63 inch diameter	51.0		34.0		6.5	
91		Grade C Mg (Atomized)	50		50			
92			29.2		50.9		6	
93			36.5		63.5			
94			36.5		63.5			
95			33.2		57.7		6	
96			31.8		55.2		6	
97			34.7		60.5		6	
98		Grade A Mg Atomized	36.5		63.5			
99		Grade A Mg Atomized	40					32
100		Grade C Mg (Ground)	36.5		63.5			
101		Grade C Mg (Atomized)	40		60			
102			27.3		63.6		6	
103			38.2		57.1		6	
104			25.0		58.4		6	
105			36.5		63.5			
106			31.8		55.2		6	
107			39.6		59.5		6	
108		Grade A Mg Atomized	40		60			
109			34.7		60.5		6	
110			60.8		26.1		6	
111			36.1		63.0		6	
112			40		60			
113			38.2		57.1		6	
114			36.4		54.5		6	
115	FR-508		30	9	42		6.5	
116		Grade A Mg Atomized	30					33
117			26.1		60.8		6	
118		Grade C Mg (Atomized)	36.5		63.5			
119			29.7		69.4		6	
120			27.3		63.6		6	
121			72.7		18.2		6	
122		Grade A Mg Atomized	30		70			
123		Grade C Mg (Ground)	30		70			
124			30		70			
125			26.1		60.8		6	
126			33.2		57.7		6	

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
127			60.8		26.1		6	
128			28.6		66.6		6	
129			24.0		56.0		6	
130			30		70			
131			30		70			
132			28.6		66.6		6	
133			65.2		21.7		6	
134			69.5		17.4		6	
135		Grade A Mg Atomized	30					32
136		Grade C Mg (Atomized)	30		70			
137			48.0		32.0		6	
138		Grade A Mg Atomized	20		80			
139			20		80			
140			58.4		25.0		6	
141			69.5		17.4		6	
142			66.7		16.7		6	
143			17.4		69.5		6	
144			18.2		72.7		6	
145			19		76		6	
146			16.7		66.7		6	
147			19		76		6	
148			77.3		13.6		6	
149			19.8		79		6	
150			18.2		72.7		6	
151		Grade A Mg Atomized	20					33
152		Grade A Mg (Ground)	20		80			
153			20		80			
154			73.8		13.0		6	
155			17.4		69.5		6	
156		Grade C Mg (Atomized)	20		80			
157		Grade C Mg (Ground)	20		80			
158	Batch 7		47.5		47.5		5	
159	T7E1	Aircraft Flare (guide)						
160	AN-M37A2	Aircraft Illum. Signal (Dbl.-Star)						
161	AN-M37A1	Aircraft Illum. Signal (Dbl.-Star) (R-R)						
162	AN-M37	Aircraft Illum. Signal (Dbl.-Star) (R-R)						
163	AN-M40A2	Aircraft Illum. Signal (Dbl.-Star) (R-Y)						
164	AN-M40A1	Aircraft Illum. Signal (Dbl.-Star) (R-Y)						
165	AN-M40	Aircraft Illum. Signal (Dbl.-Star) (R-Y)						
166	AN-M41A2	Aircraft Illum. Signal (Dbl.-Star) (R-G)						
167	AN-M41A1	Aircraft Illum. Signal (Dbl.-Star) (R-G)						
168	AN-M41	Aircraft Illum. Signal (Dbl.-Star) (R-G)						

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
169	AN-M43A2	Aircraft Illum. Signal (Single Star)						
170	AN-M43A1	Aircraft Illum. Signal (Single Star)						
171	AN-M43	Aircraft Illum. Signal (Single Star)						
172	AN-M53A2	Tracer, Double Star (R,Y)						
173	AN-M53A1	Tracer, Double Star (R,Y)						
174	AN-M53	Tracer, Double Star (R,Y)						
175	AN-M54A2	Tracer, Double Star (R,R)						
176	AN-M54A1	Tracer, Double Star (R,R)						
177	AN-M54	Tracer, Double Star (R,R)						
178	AN-M55A2	Tracer, Double Star (G,R)						
179	AN-M55A1	Tracer, Double Star (G,R)						
180	AN-M55	Tracer, Double Star (G,R)						
181	AN-M57A2	Tracer, Double Star (R,R)						
182	AN-M57A1	Tracer, Double Star (R,R)						
183	AN-M57	Tracer, Double Star (R,R)						
184	#1	50,000 Candle Power Rocket						
185	2	Propelled Parachute Red						
186	3	Flare Distress Signal						
187	4	Flare Distress Signal						
188	5	Flare Distress Signal						
189	6	Flare Distress Signal						
190	4		37		56		6	
191	4a		44		56			
192	6		37	7	56			
193	1						3	34.47
194	2		4.9				3	34.47
195	3		9.7				3	34.47
196	4		19.4				3	34.47
197			51		34		6.5	
198	M-52A2	Ground Illum. Signal						
199	M-52A1	Ground Illum. Signal						
200	M-158	Ground Illum. Signal						
201	M-51A1	Ground Illum. Signal (Parachute)						
202	M-126A1	Ground Illum. Signal (Parachute)						
203	M-126	Ground Illum. Signal (Parachute)						
204	M-131	Ground Illum. Signal (Parachute)						
205	AN-M75	Marine Illum. Signal						
206	M-72	Railroad Warning Fusee						
207	M-72	Railroad Warning Fusee						
208	M-72	Railroad Warning Fusee						
209	M-72	Railroad Warning Fusee						
210	MK-6	Aircraft Emerg. Ident. Signal			19.5	63.0	8	28

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
211	MK-1	Aircraft Recall Signal			20.0	65.0	8,7	28
212	MK-1-0	Color Burst Unit	16.8	12.0	24.0			7,41
213	MK-2-0	Color Burst Unit	67.2	48.0	96.0			7,41
214	MK13-0	Day & Night Distress Signal	21.0	15.0	45.0		18	6
215	MK1-0	Navy Lite Red Distress Signal			30.0			28,35,36
216	MK43-0,44-0	Drill Mine Signal	8		38		6	36,9,37,41
217	MK2	Pistol Signal Light Cartridge			18	64		28
218	MK4-0	Pistol Signal Light Cartridge			19.5	63.0	8	28
219	MK4-0	Pistol Signal Light Cartridge (Alt. Comp.)	14.9		52.8	19.4	18	6
220	MK1-2	Pistol Signal Rocket (Chameleon)				71.2	7	28,38
221	MK1-4	Pistol Signal Rocket (Occulting Chameleon)	33	40	16		7,18,2	6
222	MK1-10	Pistol Signal Rocket (Comet)				68.5	7	28,38
223	MK1-3	Pistol Signal Rocket (Shower)	33	40	16		7,18,2	6
224	MK1-1	Pistol Signal Rocket (Star)			18.8	62.4	7	28
225	M-5	Single Signal Star			19.5	63.0	8	28
226	XB-7A	Submarine Emerg. Ident. Signal	20	25	40		6,5	
227	MK3-3	Submarine Emerg. Ident. Signal	34	21	34		18	6
228	MK11,12	Submarine Emerg. Ident. Signal	17.5	25	45		6,18	
229	XM-148	Red Star Cluster	29	9	43		6,5	
230	R-45				56		6	39
231	UA-97				55		19	39
232	FR-534	Ground Signal XM-145 & 146	29	9	43		6,5	
233		Grade A Mg Atomized	20					32
234		Grade C Mg (Atomized)	70		30			
235		Grade A Mg (Ground)	20		80			
236		Grade A Mg (Ground)	19		76		18	
237		Grade A Mg (Ground)	18.2		72.7		18	
238		Grade A Mg (Ground)	16.6		66.7		18	
239		Grade A Mg (Ground)	30		70			
240		Grade A Mg (Ground)	28.6		66.6		18	
241		Grade A Mg (Ground)	27.3		63.6		18	
242		Grade A Mg (Ground)	25.0		58.4		18	
243		Grade A Mg (Ground)	40		60			
244		Grade A Mg (Ground)	38.2		57.1		18	
245		Grade A Mg (Ground)	36.4		54.5		18	
246		Grade A Mg (Ground)	33.4		50.0		18	
247		Grade A Mg (Ground)	50		50			
248		Grade A Mg (Ground)	47.6		47.6		18	
249		Grade A Mg (Ground)	45.5		45.5		18	
250		Grade A Mg (Ground)	41.7		41.7		18	
251		Grade A Mg (Ground)	60		40			
252		Grade A Mg (Ground)	70		30			

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
253		Grade A Mg (Ground)	66.6		28.6		18	
254		Grade A Mg (Ground)	63.6		27.3		18	
255		Grade A Mg (Ground)	58.4		25.0		18	
256		Grade A Mg (Ground)	85		15			
257		Grade A Mg (Ground)	81		14.3		18	
258		Grade A Mg (Ground)	77.3		13.6		18	
259		Grade A Mg (Ground)	70.8		12.5		18	
260		Grade A Mg (Ground)	19		76		20	
261		Grade A Mg (Ground)	18.2		72.7		20	
262		Grade A Mg (Ground)	16.6		66.7		20	
263		Grade A Mg (Ground)	28.6		66.6		20	
264		Grade A Mg (Ground)	27.3		63.6		20	
265		Grade A Mg (Ground)	25.0		58.4		20	
266		Grade A Mg (Ground)	38.2		57.1		20	
267		Grade A Mg (Ground)	36.4		54.5		20	
268		Grade A Mg (Ground)	33.4		50.0		20	
269		Grade A Mg (Ground)	47.6		47.6		20	
270		Grade A Mg (Ground)	45.5		45.5		20	
271		Grade A Mg (Ground)	41.7		41.7		20	
272		Grade A Mg (Ground)	66.6		28.6		20	
273		Grade A Mg (Ground)	63.6		27.3		20	
274		Grade A Mg (Ground)	58.4		25.0		20	
275		Grade A Mg (Ground)	81.0		14.3		20	
276		Grade A Mg (Ground)	77.3		13.6		20	
277		Grade A Mg (Ground)	70.8		12.5		20	
278		Grade A Mg (Ground)	19		76		6	
279		Grade A Mg (Ground)	18.2		72.7		6	
280		Grade A Mg (Ground)	16.6		66.7		6	
281		Grade A Mg (Ground)	28.6		66.6		6	
282		Grade A Mg (Ground)	27.3		63.6		6	
283		Grade A Mg (Ground)	25.0		58.4		6	
284		Grade A Mg (Ground)	23.1		53.8		6	
285		Grade A Mg (Ground)	38.2		57.1		6	
286		Grade A Mg (Ground)	36.4		54.5		6	
287		Grade A Mg (Ground)	33.4		50.0		6	
288		Grade A Mg (Ground)	30.8		46.2		6	
289		Grade A Mg (Ground)	47.6		47.6		6	
290		Grade A Mg (Ground)	45.5		45.5		6	
291		Grade A Mg (Ground)	41.7		41.7		6	
292		Grade A Mg (Ground)	38.4		38.4		6	
293		Grade A Mg (Ground)	66.6		28.6		6	
294		Grade A Mg (Ground)	63.6		27.3		6	

TABLE XVIII. COMPOSITION CODE, RED FLARES (Continued)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
295		Grade A Mg (Ground)	58.4		25.0		6	
296		Grade A Mg (Ground)	53.8		23.1		6	
297		Grade A Mg (Ground)	81.0		14.3		6	
298		Grade A Mg (Ground)	77.3		13.6		6	
299		Grade A Mg (Ground)	70.8		12.5		6	
300		Grade A Mg (Ground)	28.6		66.6		21	
301		Grade A Mg (Ground)	27.3		63.6		21	
302		Grade A Mg (Ground)	38.2		57.1		21	
303		Grade A Mg (Ground)	36.4		54.5		21	
304		Grade A Mg (Ground)	47.6		47.6		21	
305		Grade A Mg (Ground)	45.5		45.5		21	
306		Grade A Mg (Ground)	66.6		28.6		21	
307		Grade A Mg (Ground)	63.6		27.3		21	
308		Grade A Mg (Ground)	19		76			40
309		Grade A Mg (Ground)	18.2		72.7			40
310		Grade A Mg (Ground)	16.6		66.7			40
311		Grade A Mg (Ground)	15.4		61.5			40
312		Grade A Mg (Ground)	28.6		66.6			40
313		Grade A Mg (Ground)	27.3		63.6			40
314		Grade A Mg (Ground)	25.0		58.4			40
315		Grade A Mg (Ground)	23.1		53.8			40
316		Grade A Mg (Ground)	38.2		57.1			40
317		Grade A Mg (Ground)	36.4		54.5			40
318		Grade A Mg (Ground)	33.4		50.0			40
319		Grade A Mg (Ground)	30.8		46.2			40
320		Grade A Mg (Ground)	47.6		47.6			40
321		Grade A Mg (Ground)	45.5		45.5			40
322		Grade A Mg (Ground)	41.7		41.7			40
323		Grade A Mg (Ground)	38.4		38.4			40
324		Grade A Mg (Ground)	57.1		38.2			40
325		Grade A Mg (Ground)	54.5		36.4			40
326		Grade A Mg (Ground)	50.0		33.4			40
327		Grade A Mg (Ground)	46.2		30.8			40
328		Grade A Mg (Ground)	66.6		28.6			40
329		Grade A Mg (Ground)	63.6		27.3			40
330		Grade A Mg (Ground)	58.4		25.0			40
331		Grade A Mg (Ground)	53.8		23.1			40
332		Grade A Mg (Ground)	19		76			6
333		Grade A Mg (Ground)	18.2		72.7			6
334		Grade A Mg (Ground)	16.6		66.7			6
335		Grade A Mg (Ground)	28.6		66.6			6
336		Grade A Mg (Ground)	27.3		63.6			6

TABLE XVIII. COMPOSITION CODE, RED FLARES (Concluded)

Index	Manufact. Code	Designation	Mg	$KClO_4$	$Sr(NO_3)_2$	$KClO_3$	Binder	Misc.
337			25.0		58.4		6	6
338			23.1		53.8		6	6
339			38.2		57.1		6	6
340			36.4		54.5			6
341			33.4		50.0			6
342			30.8		46.2			6
343			47.6		47.6			6
344			45.5		45.5			6
345			41.7		41.7			6
346			38.4		38.4			6
347			66.6		28.6			6
348			63.6		27.3			6
349			58.4		25.0			6
350			53.8		23.1			6
351			81.0		14.3			6
352			77.3		13.6			6
353			70.8		12.5			6
354			85		15			
355	XM-16A	Drill Mine Signal	8.3		39.5		6	9, 37, 36, 41
356	T-15	Aircraft Parachute Flare	40.0	22.0	18.0		18	6

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
1	126			60										9
2	127		60				40							
3	125		60											9
4	123		60								40			
5	F17-80	2.74 inch diameter	61		30								15, 16	
6	124			50							40			
7	F17-80	2.0 inch diameter	61		30								15, 16	
8	F17-80	1.31 inch diameter	61		30								15, 16	
9	F17-80	2.6 inch diameter	61		30								15, 16	
10	F17-80	4.7 inch diameter	61		30								15, 16	
11	Nitelite													
12		Gran 18 Mg 2.75 inch diameter	61.3		33.1								5	
13		Gran 17 Mg 2.75 inch diameter	66.0		28.4								5	
14	Standard												15	
15	F17-80	2.0 inch diameter	61		30								15, 16	
16	F17-80	1.32 inch diameter	61		30								15, 16	
17		Gran 18 Mg 2.75 inch diameter	56.6		37.8								5	
18		Gran 17 Mg 2.75 inch diameter	70.7		23.7								5	
19		Gran 17 Mg 2.75 inch diameter	61.3		33.1								5	
20		Gran 15 Mg 1.75 inch diameter	70.7		23.7								5	
21		Gran 15 Mg 1.75 inch diameter	66.0		28.4								5	
22		50/100 Mg Paraffin Case Coating 15,000 psi	48		42								5, 6	
23	XM-170												15	
24	XM-170												15	
25	XM-170												15	
26	MK24 Mod 2													
27		Gran 17 Mg 2.75 inch diameter	56.6		37.8								5	27
28		Gran 15 Mg 2.75 inch diameter	70.7		23.7								5	
29		Gran 15 Mg 2.75 inch diameter	66.0		28.4								5	
30		Gran 17 Mg 4.25 inch diameter	61.3		33.1								5	
31		4.18 inch diameter steel case	48		42								5, 6	
32		Gran 15 Mg 1.75 inch diameter	61.3		33.1								5	
33		Gran 17 Mg 2.75 inch diameter	75.5		18.9								5	
34		Gran 17 Mg 4.25 inch diameter	66.0		28.4								5	
35	MK-24X												15	
36	MK-24X												15	
37	MK-24X												15	
38		Gran 17 Mg 1.75 inch diameter	66.0		28.4								5	
39		50/100 Mg Amberlac Case Coating 20,000 psi	48		42								5, 6	
40		50/100 Mg Laminac Case Coating 25,000 psi	48		42								5, 6	
41		Gran 15 Mg 2.75 inch diameter	61.3		33.1								5	
42		30/50 Mg Polyethylene Case Coating 10,000 psi	48		42								5, 6	
43		Gran 17 Mg 2.75 inch diameter	51.9		42.3								5	25
44		Gran 18 Mg 4.25 inch diameter	66.0		28.4								5	
45		Gran 18 Mg 4.25 inch diameter	56.6		37.8								5	
46		50/100 Mg Laminac Case Coating 15,000 psi	48		42								5, 6	
47		Gran 17 Mg 4.25 inch diameter	56.6		37.8								5	25

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
48		30/50 Mg Laminac Case Coating 10, 000 psi	48		42								5, 6	
49		30/50 Mg Laminac Case Coating 25, 000 psi	48		42								5, 6	
50		50/100 Mg Amberlac Case Coating 25, 000 psi	48		42								5, 6	
51		Gran 18 Mg 2. 75 inch diameter	70. 7		23. 7								5	
52		50/100 Mg Polyethylene Case Coating 4, 000 psi	48		42								5, 6	
53		30/50 Mg Amberlac Case Coating 20, 000 psi	48		42								5, 6	
54		50/100 Mg Laminac Case Coating 2, 000 psi	48		42								5, 6	
55		30/50 Mg Laminac Case Coating 30, 000 psi	48		42								5, 6	
56		100/200 Mg Amberlac Case Coating 7, 000 psi	48		42								5, 6	
57		50/100 Mg Polyethylene Case Coating 25, 000 psi	48		42								5, 6	
58		100/200 Mg Laminac Case Coating 2, 000 psi	48		42								5, 6	
59	FY 1231	Balled Mg Test #11	56		36. 3								5	
60		30/50 Mg Laminac Case Coating 15, 000 psi	48		42								5, 6	
61	MK24 Mod 3													
62	F17-80	4. 7 inch diameter	61		30								15, 16	
63		30/50 Mg Amberlac Case Coating 10, 000 psi	48		42								5, 6	
64		30/50 Mg Amberlac Case Coating 15, 000 psi	48		42								5, 6	
65		Gran 18 Mg 4. 25 inch diameter	61. 3		33. 1								5	26
66		30/50 Mg Polyethylene Case Coating 7, 000 psi	48		42								5, 6	
67		100/200 Mg Amberlac Case Coating 2, 000 psi	48		42								5, 6	
68		2. 75 inch diameter	48		42								5, 6	
69		4. 13 inch diameter	48		42								5, 6	
70		4. 13 inch diameter Paper Case	48		42								5, 6	
71		Gran 18 Mg 2. 75 inch diameter	66. 0		28. 4								5	26
72		30/50 Mg Amberlac Case Coating 30, 000 psi	48		42								5, 6	
73		30/50 Mg Laminac Case Coating 7, 000 psi	48		42								5, 6	
74		30/50 Mg Laminac Case Coating 20, 000 psi	48		42								5, 6	
75		50/100 Mg Amberlac Case Coating 2, 000 psi	48		42								5, 6	
76		20/50 Mg Laminac Case Coating 20, 000 psi	48		42								5, 6	
77		50/100 Mg Laminac Case Coating 10, 000 psi	48		42								5, 6	
78		50/100 Mg Polyethylene Case Coating 20, 000 psi	48		42								5, 6	
79		30/50 Mg Amberlac Case Coating 7, 000 psi	48		42								5, 6	
80		50/100 Mg Amberlac Case Coating 15, 000 psi	48		42								5, 6	
81		30/50 Mg Amberlac Case Coating 25, 000 psi	48		42								5, 6	
82		30/50 Mg Polyethylene Case Coating 30, 000 psi	48		42								5, 6	
83		50/100 Mg Amberlac Case Coating 7, 000 psi	48		42								5, 6	
84		50/100 Mg Amberlac Case Coating 10, 000 psi	48		42								5, 6	
85		50/100 Mg Paraffin Case Coating 25, 000 psi	48		42								5, 6	
86		50/100 Mg Polyethylene Case Coating 2, 000 psi	48		42								5, 6	
87			75		25									
88		100/200 Mg Amberlac Case Coating 10, 000 psi	48		42								5, 6	
89		Gran 18 Mg 1. 75 inch diameter	56. 6		37. 8								5	
90		30/50 Mg Amberlac Case Coating 4, 000 psi	48		42								5, 6	
91		30/50 Mg Amberlac Case Coating 2, 000 psi	48		42								5, 6	
92		30/50 Mg Laminac Case Coating 4, 000 psi	48		42								5, 6	
93		30/50 Mg Polyethylene Case Coating 20, 000 psi	48		42								5, 6	
94		20/50 Mg Polyethylene Case Coating 10, 000 psi	48		42								5, 6	
95		30/50 Mg Polyethylene Case Coating 25, 000 psi	48		42								5, 6	
96		50/100 Mg Laminac Case Coating 7, 000 psi	48		42								5, 6	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
97		50/100 Mg Paraffin Case Coating 20, 000 psi	48		42								5, 6	
98		100/200 Mg Amberlac Case Coating 4, 000 psi	48		42								5, 6	
99		100/200 Mg Laminac Case Coating 4, 000 psi	48		42								5, 6	
100	FY 1231	Balled Mg Test #111	56		36. 3								5	
101		Gran 17 Mg 1. 75 inch diameter	61. 3		33. 1								5	26
102		30/50 Mg Polyethylene Case Coating 15, 000 psi	48		42								5, 6	
103		20/50 Mg Laminac Case Coating 15, 000 psi	48		42								5, 6	
104		50/100 Mg Polyethylene Case Coating 7, 000 psi	48		42								5, 6	
105		Gran 15 Mg 2. 75 inch diameter	75. 5		18. 9								5	
106		Gran 17 Mg 4. 25 inch diameter	75. 5		18. 9								5	
107		50/100 Mg Laminac Case Coating 4, 000 psi	48		42								5, 6	
108		100/200 Mg Paraffin Case Coating 4, 000 psi	48		42								5, 6	
109		50/100 Mg Paraffin Case Coating 4, 000 psi	48		42								5, 6	
110	Briteye X												15	
111	Briteye X												15	
112	Briteye X												15	
113		100/200 Mg Polyethylene Case Coating 2, 000 psi	48		42								5, 6	
114	FY 1230A	Atomized Mg Test #11	56		36. 3								5	
115		Gran 17 Mg 1 75 inch diameter	56. 6		37. 8								5	
116		20/50 Mg Amberlac Case Coating 20. 000 psi	48		42								5, 6	
117		50/100 Mg Amberlac Case Coating 4, 000 psi	48		42								5, 6	
118		Gran 17 Mg 4. 25 inch diameter	70. 7		23. 7								5	
119		30/50 Mg Paraffin Case Coating 25, 000 psi	48		42								5, 6	
120		50/100 Mg Polyethylene Case Coating 10, 000 psi	48		42								5, 6	
121		100/200 Mg Polyethylene Case Coating 7, 000 psi	48		42								5, 6	
122		Gran 17 Mg 1. 75 inch diameter	70. 7		23. 7								5	
123		50/100 Mg Polyethylene Case Coating 15, 000 psi	48		42								5, 6	
124		100/200 Mg Amberlac Case Coating 15, 000 psi	48		42								5	
125	FY 1230	Atomized Mg Test #111	56		36. 3								5	
126		50/100 Mg Laminac Case Coating 20, 000 psi	48		42								5. 6	
127		50/100 Mg Paraffin Case Coating 2, 000 psi	48		42								5, 6	
128	FY 1230	Atomized Mg Test #11	56		36. 3								5	
129		20/50 Mg Amberlac Case Coating 25, 000 psi	48		42								5, 6	
130		100/200 Mg Polyethylene Case Coating 4, 000 psi	48		42								5, 6	
131		100/200 Mg Polyethylene Case Coating 10, 000 psi	48		42								5, 6	
132		100/200 Mg Paraffin Case Coating 2, 000 psi	48		42								5, 6	
133		20/50 Mg Amberlac Case Coating 7, 000 psi	48		42								5, 6	
134		20/50 Mg Amberlac Case Coating 10, 000 psi	48		42								5, 6	
135		20/50 Mg Polyethylene Case Coating 2, 000 psi	48		42								5, 6	
136		100/200 Mg Paraffin Case Coating 25, 000 psi	48		42								5, 6	
137		20/50 Mg Laminac Case Coating 7, 000 psi	48		42								5, 6	
138		20/50 Mg Polyethylene Case Coating 15, 000 psi	48		42								5, 6	
139		50/100 Mg Paraffin Case Coating 7, 000 psi	48		42								5, 6	
140		Gran 15 Mg 2. 75 inch diameter	56. 6		37. 8								5	
141		20/50 Mg Laminac Case Coating 4, 000 psi	48		42								5, 6	
142		20/50 Mg Polyethylene Case Coating 25, 000 psi	48		42								5, 6	
143		100/200 Mg Laminac Case Coating 7, 000 psi	48		42								5, 6	
144		Gran 18 Mg 1. 75 inch diameter	70. 7		23. 7								5	
145		100/200 Mg Amberlac Case Coating 20, 000 psi	48		42								5, 6	
146		100/200 Mg Laminac Case Coating 20, 000 psi	48		42								5, 6	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
147		20/50 Mg Paraffin Case Coating 15,000 psi	48		42								5,6	
148		30/50 Mg Paraffin Case Coating 15,000 psi	48		42								5,6	
149		20/50 Mg Laminac Case Coating 10,000 psi	48		42								5,6	
150		50/100 Mg Paraffin Case Coating 10,000 psi	48		42								5,6	
151		20/50 Mg Polyethylene Case Coating 4,000 psi	48		42								5,6	
152		20/50 Mg Polyethylene Case Coating 20,000 psi	48		42								5,6	
153		30/50 Mg Paraffin Case Coating 7,000 psi	48		42								5,6	
154		3.88 inch diameter Steel-paper Liner	48		42								5,6	
155		20/50 Mg Amberlac Case Coating 25,000 psi	48		42								5,6	
156		20/50 Mg Polyethylene Case Coating 7,000 psi	48		42								5,6	
157		100/200 Mg Laminac Case Coating 10,000 psi	48		42								5,6	
158		100/200 Mg Polyethylene Case Coating 15,000 psi	48		42								5,6	
159		100/200 Mg Paraffin Case Coating 7,000 psi	48		42								5,6	
160		30/50 Mg Paraffin Case Coating 20,000 psi	48		42								5,6	
161		100/200 Mg Laminac Case Coating 25,000 psi	48		42								5,6	
162	341		60								40			
163		20/50 Mg Amberlac Case Coating 4,000 psi	48		42								5,6	
164		100/200 Mg Paraffin Case Coating 15,000 psi	48		42								5,6	
165		Gran 15 Mg 1.75 inch diameter	56.6		37.8								5	
166		20/50 Mg Amberlac Case Coating 15,000 psi	48		42								5,6	
167		100/200 Mg Amberlac Case Coating 25,000 psi	48		42								5,6	
168		30/50 Mg Laminac Case Coating 2,000 psi	48		42								5,6	
169		30/50 Mg Polyethylene Case Coating 4,000 psi	48		42								5,6	
170		14,000 psi Gran 17 Mg	50		50								5	
171		Gran 17 Mg 1.75 inch diameter	51.9		42.3								5	
172		100/200 Mg Laminac Case Coating 15,000 psi	48		42								5,6	
173		100/200 Mg Paraffin Case Coating 20,000 psi	48		42								5,6	
174	FY 1231	Balled Mg Test #1	56		36.3								5	
175		Gran 18 Mg 2.75 inch diameter	51.9		42.3								5	
176		20/50 Mg Paraffin Case Coating 10,000 psi	48		42								5,6	
177		30/50 Mg Polyethylene Case Coating 2,000 psi	48		42								5,6	
178		20/50 Mg Paraffin Case Coating 20,000 psi	48		42								5,6	
179		100/200 Mg Polyethylene Case Coating 25,000 psi	48		42								5,6	
180		20/50 Mg Paraffin Case Coating 25,000 psi	48		42								5,6	
181		Gran 17 Mg 4.25 inch diameter	51.9		42.3								5	26
182		Gran 18 Mg 2.75 inch diameter	47.2		47.2								5	
183		100/200 Mg Polyethylene Case Coating 20,000 psi	48		42								5,6	
184		30/50 Mg Paraffin Case Coating 10,000 psi	48		42								5,6	
185		20/50 Mg Laminac Case Coating 2,000 psi	48		42								5,6	
186		30/50 Mg Paraffin Case Coating 4,000 psi	48		42								5,6	
187		Gran 18 Mg 4.25 inch diameter	51.9		42.3								5	
188			70		30									
189		Gran 18 Mg 1.75 inch diameter	75.5		18.9								5	
190	FY 1230A	Atomized Mg Test #111	56		36.3								5	
191		20/50 Mg Paraffin Case Coating 7,000 psi	48		42								5,6	
192		Gran 17 Mg 1.75 inch diameter	75.5		18.9								5	
193		Gran 15 Mg 2.75 inch diameter	51.9		42.3								5	
194		Gran 18 Mg 1.75 inch diameter	51.9		42.3								5	
195		30/50 Mg Paraffin Case Coating 2,000 psi	48		42								5,6	
196		1.80 inch diameter	48		42								5,6	
197	SUU-7	Parachute Flare Cartridge	63		31								5	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
198		Gran 15 Mg 1.75 inch diameter	75.5		18.9								5	
199		16,300 psi Gran 17 Mg	50		50								5	
200		Gran 15 Mg 1.75 inch diameter	51.9		42.3								5	
201		100/200 Mg Paraffin Case Coating 10,000 psi	48		42								5, 6	
202		11,600 psi Gran 17 Mg	50		50								5	
203		20/50 Mg Paraffin Case Coating 4,000 psi	48		42								5, 6	
204		20/50 Mg Amberlac Case Coating 2,000 psi	48		42								5, 6	
205		4,650 psi Gran 17 Mg	50		50								5	
206	FY 1193	No ambient storage	60		34								9	
207		9,300 psi Gran 17 Mg	50		50								5	
208		7,000 psi Gran 17 Mg	50		50								5	
209		20/50 Mg Paraffin Case Coating 2,000 psi	48		42								5, 6	
210		Gran 18 Mg 1.75 inch diameter	66.0		28.4								5	
211		Gran 15 Mg 2.75 inch diameter	47.2		47.2								5	
212		Gran 17 Mg 2.75 inch diameter	47.2		47.2								5	
213		Gran 18 Mg 4.25 inch diameter	70.7		23.7								5	
214		2.38 inch diameter	48		42								5, 6	
215			85		15									
216		Gran 18 Mg 4.25 inch diameter	47.2		47.2								5	
217		18,600 psi Gran 17 Mg	50		50								5	
218	FY 926		49		43								5	
219	FY 1193	1 Year Ambient storage	60		34								9	
220	FY 1230A	Atomized Mg Test #1	56		36.3								5	
221		9,300 psi Gran 15 Mg	50		50								5	
222		7.5" verticle candle												
223		11,600 psi Gran 16 Mg	50		50								5	
224		Gran 17 Mg 1.75 inch diameter	47.2		47.2								5	
225		2 Week 76°C storage	60		34								9	
226		9,300 psi Gran 16 Mg	50		50								5	
227	349		52.2								34.8		6	
228			60		40									
229	1216		80		20									
230		4,650 psi Gran 15 Mg	50		50								5	
231		7,000 psi Gran 15 Mg	50		50								5	
232		9,300 psi Gran 18 Mg	50		50								5	
233		Gran 15 Mg 1.75 inch diameter	47.2		47.2								5	
234		4,650 psi Gran 16 Mg	50		50								5	
235		16,300 psi Gran 18 Mg	50		50								5	
236			80		20									
237		16,300 psi Gran 15 Mg	50		50								5	
238		18,600 psi Gran 15 Mg	50		50								5	
239		7.5 psi horizontal candle												
240		Gran 18 Mg 1.75 inch diameter	61.3		33.1								5	
241		7,000 psi Gran 16 Mg	50		50								5	
242		18,600 psi Gran 16 Mg	50		50								5	
243		Gran 15 Mg 4.25 inch diameter	56.6		37.9								5	
244		14,000 psi Gran 15 Mg	50		50								5	
245	FY 1193	1 Month ambient storage	60		34								9	
246		4,650 psi Gran 18 Mg	50		50								5	
247		14,000 psi Gran 16 Mg	50		50								5	
248	FY 1193	2 Week ambient storage	60		34								9	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
249	FY 1193	6 Months ambient storage	60		34								9	
250		7,000 psi Gran 18 Mg	50		50								5	
251	FY 1193	3 Months 76°C storage	60		34								9	
252		16,300 psi Gran 16 Mg	50		50								5	
253		Gran 15 Mg 4.25 inch diameter	70.7		23.7								5	
254		11,600 psi Gran 15 Mg	50		50								5	
255		11,600 psi Gran 18 Mg	50		50								5	
256		Gran 15 Mg 4.25 inch diameter	66.0		28.4								5	
257		18,600 psi Gran 18 Mg	50		50								5	
258		14,000 psi Gran 18 Mg	50		50								5	
259	M49A1	Trip Flare												
260		Gran 15 Mg 4.25 inch diameter	75.5		18.9								5	
261		Gran 15 Mg 4.25 inch diameter	51.9		42.3								5	
262	128			60			40							
263		Gran 17 Mg 4.25 inch diameter	47.2		47.2								5	
264	FY 1193	1 Year 76°C storage	60		34								9	
265		Gran 18 Mg 2.75 inch diameter	75.5		18.9								5	
266	FY 1193	6 Months 76°C storage	60		34								9	
267	Batch No. W		57.0		19.0							19.0	5	
268		Gran 15 Mg 4.25 inch diameter	47.2		47.2								5	
269	FY 1192	No ambient storage	65.9		34.1									
270	FY 1193	3 Months ambient storage	60		34								9	
271	FY 1193	1 Month ambient storage	60		34								9	
272	FY 1192	1 Year ambient storage	65.9		34.1									
273	Batch No. J		51.7		12.7							29.6	5	
274	FY 1192	2 Week 76°C storage	65.9		34.1									
275	FY 1192	1 Year 76°C storage	65.9		34.1									
276	Batch No. C		51.7		29.60							12.7	5	
277	FY 1192	6 Months 76°C storage	65.9		34.1									
278	Batch No. Q		52.8		30.3							12.9	5	
279	Batch No. D		51.7		29.60							12.7	5	
280	FY 1192	6 Months ambient storage	65.9		34.1									
281		Gran 18 Mg 4.25 inch diameter	75.5		18.9								5	
282		Gran 15 Mg 4.25 inch diameter	61.3		33.1								5	
283	FY 1192	2 Week ambient storage	65.9		34.1									
284	Batch No. U		46.5		23.25							23.25	5	
285	FY 1192	3 Months 76°C storage	65.9		34.1									
286			46		54									
287			50		50									
288	Batch No. G		51.7		12.7							29.6	5	
289	Batch No. S		52.8		30.3							12.9	5	
290	FY 1192	1 Month ambient storage	65.9		34.1									
291	1217		70		30									
292	Batch No. L		42.3		36.2							15.5	5	
293	Batch No. O		52.8		13.0							30.2	5	
294	Batch No. A		47.5		23.75							23.75	5	
295		50/100 Mg	46.5		52.5									
296	FY 1192	1 Month 76°C storage	65.9		34.1									
297	Batch No. M		52.8		13.0							30.2	5	
298	Batch No. T		47.5		23.75							23.75	5	
299	FY 1192	3 Months ambient storage	65.9		34.1									

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
300	Batch No. K		47.5		23.75							23.75	5	
301		1.31 inch diameter	48		42								5, 6	
302	Batch No. B		47.5		23.75							23.75	5	
303		30/50 Mg	46.5		52.5								9	
304			42		58									
305			41								59			
306			70								30			
307			50								50			
308	Batch No. N		42.3		36.2							15.5	5	
309	Batch No. V		48.5		24.25							24.25	5	
310	Batch No. I		43.25		37.0							15.85	5	
311	1214		60		40									
312	MK24 Mod		58		42									
313	Batch No. P		42.3		15.5							36.2	5	
314	342		57.2								38.1		6	
315	Batch No. H		43.25		37.0							15.85	5	
316	206-F4		40		30									22
317	FY 1204				30									2
318			80								20			
319		200/325 Mg	46.5		52.5									
320		0.63 inch diameter	48		42								5, 6	
321	1174				38									4
322			60								40			
323	1203				20									2
324	350		52.2								34.8			
325	FY 1187				40									2
326	FY 985				43									10
327	Batch No. R		42.3		15.5							36.2	5	
328	1209				20									2, 3
329	Batch No. E		43.25		15.8							37.0	5	
330	1208				30									2, 3
331			30		70									
332	Batch No. F		43.25		15.8							37.0	5	
333			70				30							
334			30								70			
335	1206				20									3
336	1189				10									2, 3
337			42				58							
338			50				50							
339			60				40							
340			75				25							
341	1188				30									3
342			85								15			
343	1210				40									2, 3
344	1211				31.5									4
345			38				62							
346			60				40							
347	1212				10									3
348	1215		90		10									
349	1207				40									3

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
350	1205				10									2
351			57.2				38.1						6	
352	354		52.2				34.8							
353			80				20							
354	201-F3		40		60									
355	105-F1		35		65									
356	1175				24.1									5
357	378		52.2								34.8			
358			54.5				36.4						6	
359	353		52.2				34.8							
360	219-F9		65		35									
361	351		52.2								34.8			
362	70-F12		42											23
363	355		52.2				34.8							
364	348		52.2				34.8							
365			52.2				34.8							
366			20		80									
367	92-F13													23, 10
368	7-F12		42											23
369	380		52.2				34.8							
370	FW 185		60				40							
371	78-F12		42											23
372	69-F12		42											23
373	79-F12		42											23
374	FW 262													4, 20
375	68-2F12		42											23
376	11-F13													23, 10
377	186-F13													23, 10
378			20								80			
379	185-F13													23, 10
380	24-F12		42											23
381	94-F10		70		30									
382	FW 253		5											4, 16, 17
383	122		28								72			
384	21-F13													23, 10
385	344		52.2								34.8		6	
386	344		52.2								34.8		6	
387	193-F2		35		10									22
388	343		54.5								36.4		6	
389	FW 260													4, 8
390			20				80							
391	FW 251													4, 16, 17
392	FW 250													4, 17
393	FW 252													4, 16, 17
394	FW 240													4, 14
395	212													9
396	FW 247													4
397	FW 248													4
398	216										80			
399			30				70							
400	FW 244													4

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
401	FW 243													4
402	FW 263													4, 21
403	211													9
404	214										80			
405	FW 239													4, 15, 16
406	FW 234		10											11, 12
407	210													9
408	215										80			
409	121		20								80			
410	FW 238		15											
411	FW 261													4, 19
412	DP 563		5											11, 12
413	FW 233													4
414	213										80			
415	209													9
416	MK6	Aircraft Emergency Identification Signal	6	14		38	38						1, 2	
417	MK4-1	Aircraft Flare		13		76.5		5					3	
418	MK10-0	Aircraft Parachute Flare	38.5	5.5		41.7			10				2, 3, 4	
419	MK11-0	Aircraft Parachute Flare	38.5	5.5		41.7			10				2, 4	
420	MK1	Aircraft Recall Signal	6	14		38	38						1, 2	
421	XA-2B	Multipurpose Aircraft Flare	58		37.5								5	
422	MK5-9	Aircraft Parachute Flare	36	4		43			12.5				2, 3, 4	
423	MK5-10	Aircraft Parachute Flare	48		21	21			5				2, 3, 4	
424	MK6-6	Aircraft Parachute Flare	38.5	5.5		41.5			10				2, 3, 4	
425	MK8-1, 2	Aircraft Parachute Flare	37.1	6.5		39.3			10				2, 3, 4	
426	MK1-0	Trip-wire Flare		19		64		5	10				3	
427	MK15	Torpedo Boat Float Flare	11	10		63		5	11				3	
428	MK1	Illuminating Hand Grenade		19		42		5	10				3	
429	MK4-7, 10-0	Illuminating Projectile Load	35	2		53							4	
430	MK1-2	Navy Distress Signal Light (White)(Hand Type)	3							70			2, 6	
431	MK1-4	Pistol Rocket Signal (Occulting Chameleon)		19.7		67.6		4.2	8.2					
432	MK1-10	Pistol Rocket Signal (Comet)		14.3		65.2		4.1	8.2				7	
433	MK3-10	Pistol Rocket Signal (Shower)		13.1		70.8	1.5	6.2					7	1
434	MK1-3	Pistol Rocket Signal (Shower)		13.3		70.7	1.6	6.6					7	1
435	MK1-1	Pistol Rocket Signal (Star)		13.3		74	1.7	6.6					7	1
436	MK5	Single Signal Star		19		64		5			12			
437	XB-7A	Submarine Emergency Identification Signal	30						19			35	5 6	
438	MK11, 12	Submarine Emergency Identification Signal		19		64		5	10				3	
439	MK1-1	Target Rocket Flare	7	14		67		5	17				3	
440	MK2	Pistol Signal Light Cartridge				13	54	13					7	1
441	MK4-0	Pistol Signal Light Cartridge (White)	6	14		38	38						1, 2	
442	MK4-0	Pistol Signal Light Cartridge (Yellow)		3.5			15.5		64			15.5	3, 8	
443	MK1-2	Pistol Signal Rocket (Chameleon)		13.3		70.7	1.6	6.6					7	1
444	M159 (T137E2)	White Star Cluster Ground Illum. Signal	25		50.5							17.5	5	
445	M8A1	Aircraft Parachute Flare (Yellow)	52		35								11	
446	MK5 Mod	Aircraft Parachute Flare (Yellow)	58		37								5, 10	
447	M-50	Tow Target Flare (White)		21		68		4	5				3	
448	MK24 Mod 0	Aircraft Parachute Flare	58		37.5								5	
449	MK23 Mod 0	Tracking Flare	45				15					24	5	6
450	FY 948	Paper Case			34						51		12	
451	FY 949	Paper Case			34						46		12, 13	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox.	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
452	FY 950	Paper Case	5		34						41		12, 13	
453	FY 951	Paper Case			42.5						42.5		12	
454	FY 952	Paper Case			44						44		12	
455	FY 953	Paper Case			35						53		12	
456	FY 954	Paper Case	20		80									
457	FY 955	Paper Case	25		75									
458	FY 956	Paper Case	5		34						36		12, 13	
459	FY 957	Paper Case			30						50		12, 13	
460	FY 958	Paper Case	10		25						50		12, 13	
461	FY 959	Paper Case	5		25						50		12, 13	
462	FY 960	Paper Case	23		77									
463	FY 961	Paper Case	10		20						50		12, 13	
464	FY 962	Paper Case	10		20						50		12, 13	
465	FY 963	Paper Case	10		25						50		12, 13	
466	FY 961	Phenolic Case	10		20						50		12, 13	
467	FY 963	Phenolic Case	10		25						50		12, 13	
468			20		55				20				5	
469			40		55								5	
470			20		50		5		20				5	
471			30		65								5	
472			25		60				10				5	
473			25		70								5	
474			22		63				10				5	
475			20		50				20		5		5	
476	FY 1027		46		44.2								5	
477	FY 1072		45		45								5	
478	FY 1073		41		49								5	
479	W 20		35									32		7, 8
480	K 29		17											8
481	FY 942		70		25.3								5	
482	FY 1004		69		24								5	
483	FY 1016		54		37								5	
484	FY 1019		60		31								5	
485	FY 1023		62		31								5	
486	FY 1025		56		37								5	
487	FY 1026		70		24								5	
488	FY 1024		63		31								5	
489	FY 1077		50		44								5	
490	FY 1076		55		39								5	
491	FY 1017		57		37								5	
492	FY 1075		60		34								5	
493	FY 1074		58		36								5	
494	FY 1028		60		37								9	
495	FY 1029		60		34								9	
496	FY 1030		60		31								9	
497	FY 1031		65		32								9	
498	FY 1032		65		29								9	
499	FY 1033		65		26								9	
500	FY 1034		70		27								9	
501	FY 1035		70		24								9	
502	FY 1036		70		21								9	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
503	FY 1037		60		3[illegible]								5	
504	FY 1038		60		34								5	
505	FY 1039		60		31								5	
506	FY 1040		65		32								5	
507	FY 1041		65		29								5	
508	FY 1042		65		26								5	
509	FY 1043		70		27								5	
510	FY 1044		70		24								5	
511	FY 1045		70		21								5	
512	MK24 Mod 3	3" long												
513	MK24 Mod 2													
514	Briteye	8 inch												
515	Crane Candle	8 inch												
516	MK1	Surface Flare												
517	M48	Surface Flare												
518	M49	Surface Flare												
519	MK5, Mods 3-6	Aircraft Parachute Flare												
520	MK5, Mod 9	Aircraft Parachute Flare												
521	MK5, Mod 10	Aircraft Parachute Flare												
522	MK6, Mods	Aircraft Parachute Flare												
523	MK8, Mods	Aircraft Parachute Flare												
524	MK24 Mod 1, 2, 2A	Aircraft Parachute Flare												
525	MK24, Mod 3	Aircraft Parachute Flare												
526	MK4, Mod 3	Projectile Illuminating Load												
527	MK4, Mod 4	Projectile Illuminating Load												
528	MK4, Mod 5	Projectile Illuminating Load												
529	MK4, Mod 6	Projectile Illuminating Load												
530	MK4, Mod 7	Projectile Illuminating Load												
531	MK7	Projectile Illuminating Load												
532	MK9, Mod 0	Projectile Illuminating Load												
533	MK9, Mod 1	Projectile Illuminating Load												
534	MK11	Projectile Illuminating Load												
535	MK12	Projectile Illuminating Load												
536	MK20	High Altitude Parachute Flare (Surface)												
537	MK83A2	Illuminating Cartridge 60 mm												
538	MK1	Hand Grenade												
539	T6E1	Aircraft Flare (Guide)												
540	M8A1	Aircraft Parachute Flare												
541	M9A1	Aircraft Parachute Flare												
542	M26A1	Aircraft Parachute Flare												
543	M26A1(blue bond)	Aircraft Parachute Flare												
544	M138	Aircraft Parachute Flare												
545	M139	Aircraft Parachute Flare												
546	AN-MK8 Mod 1	Aircraft Parachute Flare												
547	AN-MK8 Mod 2	Aircraft Parachute Flare												
548	M78	Aircraft Towed Flare (Amber)												
549	M136	Guided Missile Tracking Flare												
550	M137	Guided Missile Tracking Flare												
551	M76	Surface Flare (Airport)												
552	M49A1	Trip Flare												
553	M49	Trip Flare												

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Continued)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
554	AN-M38A2	Aircraft Illumination Signal (Y-Y)												
555	AN-M38A1	Aircraft Illumination Signal (Y-Y)												
556	AN-M38	Aircraft Illumination Signal (Y-Y)												
557	AN-M40A2	Aircraft Illumination Signal (R-Y)												
558	AN-M40A1	Aircraft Illumination Signal (R-Y)												
559	AN-M40	Aircraft Illumination Signal (R-Y)												
560	AN-M42A2	Aircraft Illumination Signal (G-Y)												
561	AN-M42A1	Aircraft Illumination Signal (G-Y)												
662	AN-M42	Aircraft Illumination Signal (G-Y)												
563	AN-M44A2	Aircraft Illumination Signal (Y)												
564	AN-M44A1	Aircraft Illumination Signal (Y)												
565	AN-M44	Aircraft Illumination Signal (Y)												
566	AN-M53A2	Tracer, Double Star (Y-R-Y)												
567	AN-M53A1	Tracer, Double Star (Y-R-Y)												
568	AN-M53	Tracer, Double Star (Y-R-Y)												
569	AN-MK5 Mod 4	Aircraft Illumination Signal												
570	AN-MK6 Mod 3	Aircraft Illumination Signal												
571	AN-MK6 Mod 2	Aircraft Illumination Signal												
572	M18A2	Ground Illumination Signal (White)												
573	M18A1	Ground Illumination Signal (White)												
574	M22A1	Ground Illumination Signal (Amber)												
575	M159	Ground Illumination Signal (White)												
576	M17A1	Ground Illumination Signal (White)												
577	M21A1	Ground Illumination Signal (Amber)												
578	M127A1	White Star Parachute Signal												
579	M127	White Star Parachute Signal												
580	AN-MK13, Mod 0	Marine Smoke & Illum. Signal												
581	M118	Booby Trap Simulator												
582	Batch No. X		38.0		28.5							28.5	5	
583	Batch No. Y		47.5		47.5								5	
584	Batch No. AA		47.5		23.75							23.75	5	
585	Batch No. BB		47.5		23.75							23.75	5	
586	Batch No. CC		47.5		23.75							23.75	5	
587	Batch No. DD		47.5		23.75							23.75	5	
588	Batch No. EE		47.5		23.75							23.75	5	
589	Batch No. FF		47.5		23.75							23.75	5	
590	XM 149	White Star Cluster (FY 1054)	36		40						10		5.17	
591		Project Firefly III												24
592	MK24		60		35.5								5	
593	MK24 Mod 3		58		37.5								14	
594	MK24 Mod 3		58		37.5								14	
595	MK24 Mod 3		62		35								14	
596	MK24 Mod 3		62		35								14	
597	MK24 Mod 3		62		35								14	
598	MK24 Mod 3		62		35								14	
599	MK24 Mod 3		62		35								14	
600	MK24 Mod 3		62		35								14	
601	MK24 Mod 3		62		35								14	
602	MK24 Mod 3		62		35								14	
603	MK24 Mod 3		62		35								14	

TABLE XIX. COMPOSITION CODE, YELLOW AND WHITE FLARES (Concluded)

Index	Manufact. Code	Designation	Mg	Al	Na NO_3	Ba $(NO_3)_2$	K NO_3	Sulfur	Na Ox	$KClO_3$	$KClO_4$	Sr $(NO_3)_2$	Binder	Misc.
604	MK24 Mod 3		62		35								14	
605	MK24 Mod 3		62		35								14	
606	MK24 Mod 3		58		37.5								14	
607	MK24 Mod 3		58		37.5								14	
608	MK24 Mod 3		58		37.5								14	
609	FW 232		5											12, 13
610	FW 245													4

TABLE XX. COMPOSITION CODE, GREEN FLARES

Index	Manufact. Code	Designation or Variable	Mg	Al	S	$Ba(NO_3)_2$	$KClO_4$	$BaClO_3$ H_2O	$BaCl_2$	Binder	Misc.
1			60			40					
2			70			30					
3			32			68					
4			36			64					
5			50			50					
6			40			60					
7	FG568	6 months ambient storage	33			44	9.9			17	
8	FG568	6 months ambient storage	33			44	9.9			17	
9	245		40					55		5	
10	FG568	No ambient storage	33			44	9.9			17	
11	FG568	2 weeks 76°C storage	33			44	9.9			17	
12		Flare Diam 4.13 - Paper Case	40			35	10			6.5	
13		Flare Diam. 4.13 - Paper Case	40			35	10			6.5	
14		6 months ambient storage	31.6			42.1	9.5			17.9	
15	FG568	3 months 76°C storage	33			44	9.9			17	
16	304		40					46	9	5	
17	253		40					53		5	6
18	FG568	1 year 76°C storage	33			44	9.9			17	
19	303		40					49	6	5	
20	FG568	3 months ambient storage	33			44	9.9			17	
21	FG150		37			22.5	22.5			6.5	
22	255		40					49		5	6
23	254		40					51		5	6
24	283		40					53		22.5	
25	FG569	No ambient storage	31.6			42.1	9.5			17.9	
26	FG568	2 weeks ambient storage	33			44	9.9			17	
27	264		40					53		21.5	
28	FG465		35			22.5	22.5			6.5	
29		6 months ambient storage	31.6			42.1	9.5			17.9	
30	302		40					52	3	5	
31	255		40					51		21.5	
32		Flare Diam. 2.75 - Paper Case	40			35	10			6.5	
33	294		40					53		23.5	
34	309		40					31	24	5	
35		2 weeks ambient storage	31.6			42.1	9.5			17.9	
36	269		40					53		6.5	
37	308		40					34	21	5	
38		2 weeks 76°C storage	31.6			42.1	9.5			17.9	
39	305		40					43	12	5	
40	FG464		35			22.5	22.5			6.5	
41	FG568	1 month ambient storage	33			44	9.9			17	
42	310		40					28	27	5	
43	FG568	1 month 76°C storage	33			44	9.9			17	
44	306		40					40	15	5	
45	312		40					53		5	25
46	281		40			35	10			6	
47	270		40					51		6.5	
48	313		40					51		5	25
49	FG568	1 year ambient storage	33			44	9.9			17	
50	284		40					51		22.5	

TABLE XX. COMPOSITION CODE, GREEN FLARES (Continued)

Index	Manufact. Code	Designation or Variable	Mg	Al	S	$Ba(NO_3)_2$	$KClO_4$	BaC_2O_4, H_2O	$BaCl_2$	Binder	Misc.
51	267		40					47		21.5	
52	315		40					47		5	25
53	307		40					37	18	5	
54	271		40					49		6.5	
55		1 year ambient storage	31.6			42.1	9.5			17.9	
56	256		40					47		5	6
57	287		40					45		22.5	
58	314		40					49		5	25
59		3 months ambient storage	31.6			42.1	9.5			17.9	
60	257		40					45		5	6
61	316		40					45		5	25
62		Flare Diam. 0.63 - Paper Case	40			35	10			6.5	
63		Flare Diam. 1.31 - Paper Case	40			35	10			6.5	
64		Flare Diam. 1.80 - Paper Case	40			35	10			6.5	
65		Flare Diam. 2.38 - Paper Case	40			35	10			6.5	
66	288		40					43		22.5	
67	289		40					41		22.5	
68	285		40					49		22.5	
69		3 months ambient storage	31.6			42.1	9.5			17.9	
70	FC466		35			22.5	22.5			6.5	
71	279		40					41		5	6
72		1 month ambient storage	31.6			42.1	9.5			17.9	
73		1 year ambient storage	31.6			42.1	9.5			17.9	
74		1 month 76°C storage	31.6			42.1	9.5			17.9	
75	296		40					49		23.5	
76	290		40					39		22.5	
77	286		40					47		22.5	
78	272		40					47		6.5	
79	295		40					51		23.5	
80	278		40					43		5	6
81	273		40					45		6.5	
82	318		40					41		5	25
83	268		40					45		21.5	
84	297		40					47		23.5	
85	317		40					43		5	25
86	266		40					49		21.5	
87	298		40					45		23.5	
88	299		40					43		23.5	
89	275		40					41		6.5	
90	274		40					43		6.5	
91		Marine Location Marker	20			80					
92	280		40					39		5	6
93	301		40					39		23.5	
94	276		40					39		6.5	
95		Flare Diam. 3.88 - Steel Paper Liner	40			35	10			6.5	
96	300		40					41		23.5	
97		Flare Diam. 4.18 - Steel Case	40			35	10			6.5	
98	Formula #8		11.4			54.5				19	45
99	Formula #9		10.2			49.0				18.19	45
100	Formula #10		10.2			49.0				19	45

TABLE XX. COMPOSITION CODE, GREEN FLARES (Continued)

Index	Manufact. Code	Designation or Variable	Mg	Al	S	$Ba(NO_3)_2$	$KClO_4$	$BaClO_3 \cdot H_2O$	$BaCl_2$	Binder	Misc.
101	Formula #11		10.2			49.0				19	6, 45
102	Formula #12		11.2			53.9				19	43, 45
103	Formula #13		18.4			59.2				18, 19	
104	Formula #14					59.2				18, 19	42, 45
105	Formula #15					59.2				18, 19	42
106	Formula #16		10.2			59.2				18, 19	
107	Formula #17		5.1			59.2				18, 19	42
108	Formula #18		18.4			59.2				6, 18	
109	Formula #19					59.2				18, 19	44, 45
110	Formula #20		5.1			59.2				18, 19	44
111	Formula #21		7.1			59.2				19	44
112	Formula #22		13.3			59.2				6, 18	
113	Formula #23		18.4			59.2				6, 18	
114	Formula #24		14.9			57.4				6, 18	
115	Formula #25		15.3			59.2				6, 18	
116	Formula #26		18.4			59.2				18	25
117	Formula #27		15.3			59.2				18	25
118	Formula #28		18.4			59.2				6	
119	Formula #29		18.4			59.2				19	
120	Formula #30		18.4			59.2					25
121	Formula #31		13.3			59.2				6	
122	Formula #32		13.3			59.2				19	
123	Formula #33		10.2			59.2				6	
124	Formula #34		13.3			59.2				6	
125	Formula #35		10.2			59.2				6	
126	Formula #36		18.4			59.2					6
127	Formula #37		15.3			59.2				6	
128	Formula #38		5.4			62.4				6	44
129	Formula #39		10.2			59.2				6	44
130	Formula #40		15.3			59.2				6	44
131	Formula #41		10.2			59.2				6, 7	
132	Formula #42		6.9			22.3				19, 24	45
133	Formula #43		8.8			22.3				19, 24	
134	Formula #44		16.7			34.4	23.9			6	36
135	Formula #45		18.4			49.0				6	
136	Formula #46		10.2			59.2				6, 18	
137	Formula #47		20.4			59.2				6	
138	Formula #48		18.4			54.1				6	
139	Formula #49		10.2			59.2				18	25
140	Formula #50		15.3			59.2				6, 18	
141	Formula #51		15.3			59.2				6, 18	
142	Formula #52		12.3			39.5				6, 5	
143	Formula #53		18.4			57.2				6	43
144	Formula #54		24.5			59.2				6	
145	Formula #55		22.4			59.2				6	
146	Formula #56				18.4	59.2				6	
147	Formula #57		8.2		10.2	59.2				6	
148	Formula #58		10.2			59.2				6	44
149	Formula #59		6.4			74.4				6	44
150	Formula #60		18.4			59.2					43

TABLE XX. COMPOSITION CODE, GREEN FLARES (Continued)

Index	Manufact. Code	Designation or Variable	Mg	Al	S	$Ba(NO_3)_2$	$KClO_4$	$BaClO_3 \cdot H_2O$	$BaCl_2$	Binder	Misc.
151	Formula #61		6.6			74.4					25.44
152	Formula #62		6.6			70.3					25.44
153	Formula #63		10.5			73.7				6	
154	Formula #64		6.6			70.3				6	44
155	Formula #65		7.9			73.7				6	
156	Formula #66		7.9			68.4				6	
157	Formula #67		6.6			70.3				6	46.44
158	Formula #68					80.0					6
159	Formula #69					80.0					6
160	Formula #70					72.5				6	
161	Formula #71		12.2			59.2				6	11
162	Formula #72		6.6			74.4				6	11
163	Formula #73		5.3			73.7				6	11
164	Formula #74		7.0			73.0				6	11
165	Formula #75					73.7				6	11
166	Formula #76					68.4				6	11
167	Formula #77					79.6				6	11
168	Formula #78		2.0			73.0				6	11
169	Formula #79					79.0				6	11
170	Formula #80					75.0				6	11
171	GP-1		25			75					
172	GP-2		25			64				2	36
173	GP-3		25			65	10				
174	GP-4		25			40	22			2	36
175	GP-5		25			65				6	
176	GP-6		25			60				6,2	
177	T8E1	Aircraft Flare (Guide)									
178	M79	Aircraft Flare (Towed)									
179	AN-M39A2	Aircraft Illum. Signal Dbl-Star (G-G)									
180	AN-M39A1	Aircraft Illum. Signal Dbl-Star (G-G)									
181	AN-M9	Aircraft Illum. Signal Dbl-Star (G-G)									
182	AN-M41A2	Aircraft Illum. Signal Dbl-Star (R-G)									
183	AN-M41A1	Aircraft Illum. Signal Dbl-Star (R-G)									
184	AN-M41	Aircraft Illum. Signal Dbl-Star (R-G)									
185	AN-M42A2	Aircraft Illum. Signal Dbl-Star (G-Y)									
186	AN-M42A1	Aircraft Illum. Signal Dbl-Star (G-Y)									
187	AN-M42	Aircraft Illum. Signal Dbl-Star (G-Y)									
188	AN-M45A2	Aircraft Illum. Signal Single-Star									
189	AN-M45A1	Aircraft Illum. Signal Single-Star									
190	AN-M45	Aircraft Illum. Signal Single-Star									
191	AN-M55A2	Aircraft Illum. Signal (Tracer-Dbl Star) (G-G-R)									
192	AN-M55A1	Aircraft Illum. Signal (Tracer-Dbl Star) (G-G-R)									
193	AN-M55	Aircraft Illum. Signal (Tracer-Dbl Star) (G-G-R)									
194	AN-M54A2	Aircraft Illum. Signal (Tracer-Dbl Star) (G-R-R)									
195	AN-M54A1	Aircraft Illum. Signal (Tracer-Dbl Star) (G-R-R)									
196	AN-M54	Aircraft Illum. Signal (Tracer-Dbl Star) (G-R-R)									
197	AN-M56A2	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-G)									
198	AN-M56A1	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-G)									
199	AN-M56	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-G)									
200	AN-M58A2	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-R)									

TABLE XX. COMPOSITION CODE, GREEN FLARES (Concluded)

Index	Manufact. Code	Designation or Variable	Mg	Al	S	$Ba(NO_3)_2$	$KClO_4$	$BaClO_3 H_2O$	$BaCl_2$	Binder	Misc.
201	AN-M58A1	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-R)									
202	AN-M58	Aircraft Illum. Signal (Tracer-Dbl Star) (R-G-R)									
203	M20A1	Green Star Cluster									
204	M125A1	Green Star Cluster									
205	M19A2	Green Star Parachute									
206	MK2, Mod 0	Marine Illum. Signal									
207	MK6	Aircraft Emergency Identification Signal								8	35, 28
208	MK2	Signal Light Pistol Cartridge				40				8	35, 28
209	MK4-0	Signal Light Pistol Cartridge								8	35, 28
210	MK4-0	Signal Light Pistol Cartridge (Alternate Comp.)	14.7			67.2				2	45, 6
211	MK1-2	Pistol Signal Rocket (Chamelon)								7, 8	35, 28
212	MK1-4	Pistol Signal Rocket (Occulting Chamelon)								8	35, 28
213	MK1-10	Pistol Signal Rocket (Comet)								7, 8	35, 28
214	MK1-3	Pistol Signal Rocket (Shower)	18			50	10			3, 18, 7, 2	45, 6
215	MK1-1	Pistol Signal Rocket (Star)								7, 8	35, 28
216	MK5	Single Signal Star								8	35, 28
217	XB-7A	Submarine Emergency Identification Signal	20			14	45			6, 5	45
218	MK11 & 12	Submarine Emergency Identification Signal								8	35, 28
219	T-138	Green Star Parachute Ground Illum. Signal	35			38	10			6, 5	
220	T-12	Aircraft Parachute Flare	23			53				18	45, 6
221	XM-17A	Drill Mine Signal	20			50	10			6, 18	
222	MK13 Mod 1	Smoke or Illumination Signal	20			50	10			6, 18	
223	MK29 Mod 0	Drill Mine Signal	16			55	10			6, 18	
224	MK29 Mod 0G-3	Drill Mine Signal	16			55	10			6, 25	
225	XM-25A	Drill Mine Signal									
226	EX33 Mod 0	Marine Location Marker									
227			80			20					
228	319		40					39		5	25
229	XM-147 (FG-491)	Green Star Cluster	30.6			40.8	12.2			17, 9	
230	Formula #1		18.4			59.2				18, 9	45, 6
231	Formula #2		18.4			59.2				18, 19	45
232	Formula #3		9.2			59.2				18, 19	45, 28
233	Formula #4		9.2			59.2				18, 19	45
234	Formula #5		10.2			59.2				18, 19	45
235	Formula #6		10.2			59.2				19	45
236	Formula #7		18.4			59.2				19	45
237	3		25			65				6	
238	3a		35			65					
239	5		25			65	10				
240	7		25			65					22
241	MK3-2	Submarine Emergency Identification Signal	21			53	8			16, 2	45, 6
242	MK39-0, 40-0	Drill Mine Signal	20			50	10			6, 18	

TABLE XXI. COMPOSITION CODE, BLUE FLARES

Index	Manufact. Code	Designation	Mg	$KClO_4$	$BaO(NO_3)_2$	$PbAsO_4$	Stearic Acid	Paris Green	AP	$KClO_3$	CuCl	CuO	$CuNH_4SO_4$	AsS_3	Binder	Misc
1							11.1		74.2						4	45
2		Blue Hand Signal		78.8	19.4	36.0	3.9								2	
3							11.1		74.2						4	45
4	MKI Mod 1	BUWEPS Dr. 1129630	4.87	38.82	19.42	31.02	3.90	Subst. $PbAsO_4$							2	
5		Navy Distress Signal Light (Hand)					2			56	22	13				28
6		Navy Distress Signal Light (Hand)		39.8	19.5		8.2	32.6								
7		Navy Distress Signal Light (Hand)								53		14	19	5		28.45

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13. ABSTRACT
A detailed survey of the open and classified literature on pyrotechnics and vision has been made. A limited amount of experimentation was done to investigate the effectiveness of flickering colored light sources on target detection. The physical data on the composition of, and radiation from, green, red, blue, yellow and white flare compositions have been presented in summary tabulations. A bibliography of the reports and journal articles that were included in this is presented. The index lists the 461 entries by category; vision and visibility, pyrotechnic light sources, targets and background psychological factors. It is concluded that the most generally applicable method of improving detection of targets is simply that of minimizing glare in the observer's eyes and maximizing the illumination at the target area. None of the subtle effects proved to increase detectability appreciably. The best pyrotechnic illuminant available is the sodium nitrate magnesium flare. It appears that improvement of pyrotechnic sources can be accomplished by investigating other compositions which are selective radiators in the visible region of maximum response with minimal radiation in all other regions. A large number of tables and graphs are presented which are useful in determining visibility and illumination parameters.

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Flare Compositions						
Illuminating Flares						
Signal Flares						

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